The rivers in the North West region are currently not truly in equilibrium and modest changes in their dimensions and plan shape are discernable from year to year. Ongoing and new projects will induce morphological responses and the rivers will "react" to the changes imposed. The reactions could take the form of aggradation, degradation, changes in size or changes in plan shape.

The rate at which rivers will initially react to the works and the time which will elapse before full readjustment is achieved will depend on many factors including :

- the magnitude of changes in discharge
- the magnitude of changes in sediment supply
- the nature of the bed and bank sediments
- the size of the river
- the degree to which man-made constraints are applied

A full analysis of river morphology as affected by ongoing and new projects has not been possible during the NW regional study. However, in the following sections of this report an indication is given of the time which could elapse before re-adjustment is achieved and what the nature of that re-adjustment is likely to be. Full re-adjustment is attained asymptotically and will possibly by overtaken by future works and hydrological events. Hence these data should be taken as guidance only.

The time of re-adjustment has been categorised as follows :

- Rapid (Less than 20 years)
- Modest (20 to 50 years)
- Slow (Greater than 50 years)

4.5 Morphological assessment for each Planning Unit

4.5.1 Planning Unit 1 : Thakurgaon

Present conditions

The main rivers in this Planning Unit are the Tangaon in the central part and the Karatoya / Atrai in the West. The Dhepa is a distributary of the Karatoya / Atrai; upstream of its offtake this river is known as the Karatoya and downstream it is known as the Atrai. Analysis of the Atrai is included in Planning Unit 2 : Upper Atrai. The Dhepa joins the Punarbhaba at Dinajpur. The Karatoya / Atrai and Punarbhaba originate in India.

The area experiences inundation due to the flash floods from the upper reaches of the drainage channels in India. These flash floods generate spillage flows which lead to short duration inundation. The main problems from flash flooding lie along the Dhepa and Punarbhaba. Damage along the Tangaon is relatively minor indicating that this river is not susceptible to flash flooding. There are problems of river erosion at Panchagarh town, which is threatened by the river Karatoya; a part of the town has already been washed away by the river and the existing road bridge is under threat.

The geometry of the main rivers in Planning Unit 1 was obtained from cross-section supplied by the SWMC during the first phase of the NWRS; these are shown in Table 4.1.

TABLE 4.1
Geometry of rivers in Planning Unit 1

River	Station	Depth (m)	Top Width(m)	Slope (m/m)
Karatoya	Panchagarh	3.0	130	0.0006
Atrai	Khanshama	5.5	450	0.00038
Dhepa	Kantangon	4.0	280	0.00044
Punarbhaba	Prannagar	3.5	100	0.00024
Punarbhaba	Phulhat	3.0	180	0.00041
Tangaon	Thakatgaon	4.4	120	0.00026
Tangaon	Kodalkathi	2.5	60	0.00026

Flood frequencies for the rivers in Planning Unit 1 were obtained by analysis of discharge observations. Using the mean annual flood calculated by this hydrological analysis regime theory was used to predict the regime width and depth of flow together with the regime slope.

In order to carry out these calculations a representative sediment diameter is required together with an estimate of the sediment concentration. The SWMC have collected suspended sediment and bed sediment samples from some of the rivers in Planning Unit 1; these have been analysed to obtain sediment concentrations and sediment particle size distributions.

At Panchagarh on the Karatoya sediment concentrations of up to 600 ppm were measured; at this station a representative sediment concentration of 500 ppm was assumed for the regime analysis. At the other stations in Planning Unit 1 measured sediment concentrations were below 200 ppm; for these stations sediment concentrations of 200 ppm were assumed in the regime analysis.

Analysis of the bed sediment samples revealed D_{50} values which range from 0.23 mm to 0.4 mm; a representative sediment size of 0.4 mm was assumed for the regime analysis. The regime channel geometry, given by regime theory, for the locations in Table 4.1 are given in Table 4.2.

By comparison of the regime geometry of the rivers in Planning Unit 1 with the observed geometry the following conclusions can be drawn:

- there will be a tendency for the rivers in this Planning Unit to become narrower.
- most of the rivers in the Planning Unit will tend to become deeper.
- the Upper Purnabhaba and Tangaon have a regime slope which is steeper than the observed slope. If it is assumed that the valley slope for these rivers does not change there will be a tendency for these rivers to becomes straighter.
- the remaining rivers in Planning Unit 1 have regime slopes which are steeper than the observed slope. If it is assumed that the valley slope for these rivers does not change there will be a tendency for these rivers to become more meandering. This result may account for the fact that one of the main problems in this Planning Unit is bank erosion.

TABLE 4.2
Regime geometry of rivers in Planning Unit 1

River	Station	MAF (m_3/s)	Depth (m)	Top width (m)	Slope (m/m)
Karatoya	Panchagarh	821	4.1	124	0.00073
Atrai	Khanshama	1850	6.8	197	0.00032
Dhepa	Kantanagon	783	4.8	130	0.00034
Punarbhaba	Prannagar	121	2.3	53	0.00042
Punarbhaba	Phulhat	1064	5.5	151	0.00033
Tangaon	Thakargaon	237	3.0	73	0.00039
Tangaon	Kadalhathi	264	3.2	76	0.00039

Inherent in regime theory is an assumption about the relative erodibility of the bed and bank material and the form of flow distribution throughout the year. It could be concluded that for the rivers in the Planning Unit the erodibility of the bank material leads to rivers that are, generally, wider and shallower than the regime theory predicts. A contributing factor may also be the distortion of the flow distribution brought about by spill flows in the area.

Impact of existing developments

Tangon Barrage Project : The Tangaon Barrage is used to store water for irrigation during the dry season. It will have a minimal effect on flood flows within the Tangaon river and hence very little effect of river morphology.

Purnabhaba embankment project : The Punarbhaba embankment project could result in an increase in the discharge in the river because it reduces the spills. This could result in an increase in the depth and width of the river together with a decrease in the regime slope. If it is assumed that the valley slope for this river does not change there will be a tendency for these river to become sinuous.

There is currently a tendency for bank erosion on the Punarbhaba at Dinajpur. It is likely that this problem will become worse since regime analysis suggests that the Punarbhaba is likely to become more meandering.

Impact of proposed developments

Panchagarh town is under threat from the Karatoya and part of the town has already been lost through erosion. FAP-9A has proposed an integrated plan for flood control, drainage and river training to counter this problem. The proposed scheme involves construction of flood embankments along the Karatoya, drainage improvement and construction of river training works.

Regime analysis suggests that the Karatoya at this location has a tendency to become more meandering; this suggests that the problems at Panchagarh town are likely to become greater.

Since the main problems in this Planning Unit are due to short duration flash floods it is felt that general major structural works are not appropriate.

4.5.2 Planning Unit 2 : Upper Atrai

Present conditions

The Atrai is the main river within this Planning Unit. A morphological assessment of this river upstream of the Dhepa offtake is covered under Planning Unit 1; a morphological assessment of the Atrai downstream of the Dhepa offtake is covered under this Planning Unit. The Atrai bifurcates at Bhushirbandar into the Atrai and Kakra rivers, which rejoin at Shamjiaghat. The Little Jamuna river originates in Dinajpur district and flows southwards towards Joypurhat. This Planning Unit is not subjected to prolonged and deep flooding. The main problems are due to flash floods in the Atrai-Kakra reaches.

The geometry of the main rivers in Planning Unit 2 were obtained from cross-section supplied by the SWMC during the first phase of the NWRS; these are shown in Table 4.3.

TABLE 4.3
Geometry of rivers in Planning Unit 2

River	Station	Depth (m)	Top width (m)	Slope (m/m)
Atrai	Bushirbanda	4.7	250	0.00033
Atrai	Shamjiaghat	7.6	100	0.00022
Little Jamuna	Phulbari	2.8	25	0.00023

In Planning Unit 2 discharge observations are only available at Bushirbanda on the river Atrai. Hydrological analysis was used to estimate the mean annual flood at this station.

At other locations within Planning Unit 2 analysis of the runoff results generated by the NAM model was used to estimate the mean annual flood.

Using the estimates of the mean annual flood at different locations, regime theory was used to predict the regime width and depth of flow together with the regime slope.

In order to carry out these calculations a representative sediment diameter is required together with an estimate of the sediment concentration. The SWMC have collected suspended sediment samples at Bushirbanda and bed sediment samples from this and some other locations in Planning Unit 2; these have been analysed to obtain sediment concentrations and sediment particle size distributions.

At Bushirbanda the measured sediment concentrations were below 200 ppm; for all stations in Planning Unit 2 sediment concentrations of 200 ppm were assumed in the regime analysis.

Analysis of the bed sample particle size distributions show that the d_{50} increases in a downstream direction. A representative value of 0.2 mm was used at Bushirbanda whilst at Shamjiaghat a value of 0.5 mm was used in the regime analysis. The one bed sample taken from the Little Jamuna had a d_{50} of 0.24 mm.

The regime channel geometry for the locations in Table 4.3 are given in Table 4.4.

TABLE 4.4
Regime geometry of rivers in Planning Unit 2

River	Station	MAF	Sediment size (mm)	Depth (m)	Top width (m)	Slope (m/m)
Atrai	Bushirbanda	890	0.2	8.3	114	0.0001
Atrai	Shamjiaghat	1003	0.5	4.4	168	0.0005
Little Jamuna	Phulbari	89	0.24	2.9	36	0.0003

These results suggest that there is a tendency for the upstream parts of the Atrai to become deeper and narrower, whilst regime theory suggests that the lower part of the Atrai will become shallower and wider. Regime analysis also suggests that the upper Atrai will become more meandering and the lower Atrai straighter whereas the Little Jamuna will tend to become wider.

Impact of existing developments

The main FCD projects in this Planning Unit is the Atrai-Kakra FCD project. This project lies in the area between the river Atrai and the river Kakra. The project is ongoing and is expected to be complete in 1992-93. The regime analysis results for Bushirbanda which suggest that the Atrai will become more meandering indicate that there may be bank erosion problems on the embankments of the Atrai-Kakra project.

Impact of proposed developments

The proposed developments in this planning Unit involve the desilting of channels including the Little Jamuna. This will improve pre-monsoon drainage and during the monsoon season result in lower flood peaks and quicker evacuation of flood water.

Regime analysis suggests that the Little Jamuna is 'in regime'. If this channel is desilted there will be a tendency for it to silt up again.

As far as the desilting of minor drainage channels is concerned this will only have a long term beneficial effected if the source of sediment is eliminated.

4.5.3 Planning Unit 3 : Teesta right bank

Present conditions

The main rive in this Planning Unit is the Teesta which borders the Unit to the North. The main rivers flowing through the area are the Buri Teesta and Sati; both of these rivers are tributaries of the Teesta.

The main problems in this area are due to spillage from the Teesta. As well as causing damage within the Planning Unit these spills contribute to flows in the Ghagot and Karatoya rivers; the impact of these spills on the morphology of the Ghagot river is described in Chapter 11. In addition to spillage

from the Teesta there are some problems in both the Buri Teesta and Sati basins because of drainage congestion when water levels in the Teesta are high.

Impact of existing developments

Teesta Barrage : The Teesta barrage is one of the main features of the Teesta in this Planning in this Planning Unit. A description of the impact this barrage wil have on the morphology of the Teesta together with an analysis of both historic and possible future changes in the river's plan form is given in Chapter 11.

Impact of proposed developments

The only proposed development in this Planning Unit is the sealing of the Teesta Right Embankment (TRE). The effect of this will be to reduce damage due to spillage from the Teesta. It will also eliminate the problem of the deposition of sediment which is carried by the Teesta spills. The sealing of the TRE will not have an impact on the morphology of the river Teesta. The sealing of the embankment may result is a small rise in Teesta water level which could slightly increase the problems of drainage congestion in the Buri Teesta and Sati rivers.

If the TRE is sealed spills through it will not contribute to flows in the Ghagot and Karatoya downstream. In general the resulting reductions in discharge in these rivers will result in them becoming narrower, shallower and they will tend to follow a straighter course.

Chapter 13 contains a detailed description of the impact of sealing the TRE on the morphology of the Ghagot river.

4.5.4 Planning Unit 4 : Teesta left bank

Present conditions

The main rive in this Planning Unit is the Teesta which borders the Unit to the South. Two minor rivers Shaniajan and Sati drain the Planning Unit into the Teesta near Gaddimari and Kaunia respectively. Chapter 11 contains a detailed description of the morphology of the Teesta together with analysis of both historic and possible future changes in the rivers plan form.

The main problems in this area are due to spillage from the Teesta. This occurs because of active erosion of the Teesta left bank. There has been significant erosion during the period from 1965 to 1991; this may in part be as a result of the morphological response of the Teesta to the construction of the Teesta Right Embankment. In addition to spillage from the Teesta there are some problems in the Sati basin because of drainage congestion when water levels in the Teesta are high. Over land flow across the India border carries a significant amount of sediment which results in the silting up of inland drainage channels.

Impact of existing developments

Teesta Barrage : The Teesta barrage is one of the main features of the Teesta in this Planning Unit. A description of the impact this barrage will have on the morphology of the Teesta together with an analysis of both historic and possible future changes in the river's plan form is given in Chapter 11.

Impact of proposed developments

The main development proposed for this Planning Unit is the strengthening of the Teesta Left Embankment (TLE). The effect of this will be to reduce damage due to spillage from the Teesta. It will also eliminate the problem of the deposition of sediment which is carried by the Teesta spills. The sealing of the TLE will not have an impact on the morphology of the river Teesta. The sealing of the embankment may result is a small rise in Teesta water level which could slightly increase the problems of drainage congestion in the Sati river.

Desilting of internal drainage channels, including the Sati river, is proposed to improve drainage in the Planning Unit. These channels will tend to silt up again unless the source of the sediment in eliminated. It is understood that much of this sediment comes from India and is carried by the cross border overland flow. It is proposed to interrupt drainage paths by blocking road and railway culverts and thus prevent this sediment reaching the main drainage channels.

4.5.5 Planning Unit 5 : Kurigram

Present conditions

This Planning Unit is bounded by the Jamuna and Teesta rivers in the East and South respectively. The area is crossed by the Dharla and Dudhkumar rivers. The catchments of both of these rivers extend into India.

This Planning Unit is influenced by the long-lasting, high water levels in the Jamuna which result in backwater effects in the Teesta, Dharla and Dudhkumar. This results in drainage congestion which causes problems in these areas. A further reason for drainage congestion is the insufficient carrying capacity of some drainage channels. Problems from erosion,breaches and spills from the major rivers are a major problem. Serious erosion occurs on the right bank of the Dharla and Jamuna, and the left bank of the Teesta. Erosion is the main reason for breaches of flood embankments.

The geometry of the main rivers which cross Planning Unit 5 were obtained from cross-section supplied by the SWMC during the first phase of the NWRS; these are shown in Table 4.5.

TABLE 4.5

Geometry of rivers in Planning Unit 5

River	Station	Depth (m)	Top width (m)	Slope (m/m)
Dudhkumar	Pateswari	6.0	475	0.00009
Dharla	Tulusksimulbari	3.0	300	0.00025
Dharla	Kurigram	6.0	650	0.00025

Flood frequencies for the rivers in Planning Unit 5 were obtained by analysis of discharge observations. Using the mean annual flood calculated by this hydrological analysis the regime theory was used to predict the regime width and depth of flow together with the regime slope.

In order to carry out these calculations a representative sediment diameter is required together with am estimate of the sediment concentration. The SWMC have collected suspended sediment and bed sediment samples from some of the rivers in Planning Unit; these have been analysed to obtain sediment concentrations and sediment particle size distributions.

The analysis of the suspended sediment samples showed a wide range of concentrations; these ranged from less than 100 ppm to in excess of 1100 ppm. For the regime analysis a representative sediment concentration of 800 ppm was selected.

Analysis of the bed sediment samples revealed D_{50} values which were greater in the upstream reaches of the rivers than in the downstream reaches. This is to be expected for the rivers of this Planning Unit which flow from relatively steep land in India onto the plains in Bangladesh which have a much gentler slope. For the upstream reaches a representative particle size of 0.4 mm was selected. Representative sediment sizes of 0.15 mm and 0.2 mm were selected for the downstream reaches of the Dudhkumar and Dharla respectively.

The regime channel geometry, given by regime theory, for the locations in Table 4.5 are given in Table 4.6.

Regime analysis suggests that the main rivers in Planning Unit 5 will become deeper and narrower. The regime analysis also shows that the regime slope for the rivers is steeper than the present slope; this implies that the rivers will attempt to become straighter.

TABLE 4.6
Regime geometry of rivers in Planning Unit 5

River	Station	MAF (m^3/s)	Depth (m)	Top width (m)	Slope (m/m)
Dharla	Tulusksimulbari	1912	5.2	176	0.00100
Dharla	Kurigram	3627	7.1	170	0.00045
Dudhkumar	Pateswari	4645	6.9	138	0.00034

Impact of existing developments

Kurigram Town Protection : Kurigram town is located on the right bank of the Dharla. Bank erosion appears to be a particular problem at this location. Kurigram is situated on the inside of a large bend in the Dharla river. Regime analysis suggests that this river is attempting to become straighter; this may be the explanation for the serious bank erosion problems at Kurigram.

Kurigram North Unit and Kurigram South Unit FCD project : The result of these projects will be the almost completed embankment of the Dharla river. The impact of this is likely to be an increase in discharge which will result in the river becoming deeper and wider; it is also likely to follow a more meandering course which could further increase the problem of bank erosion.

Impact of proposed developments

The proposed developments in this Planing Unit are the completion of the projects which are already under way. The morphological impacts of these projects is described above.

4.5.6 Planning Unit 6 : Upper Karatoya

Present conditions

This Planning Unit comprises the area to the west of the Ghagot and Alai rivers as far as the Parbatipur-Saidpur railway. The main rivers flowing through the Planning Unit are the Karatoya together with its tributaries the Jamuneswari and Chikli.

There are few areas in this Planning Unit where prolonged and deep flooding regularly occurs. The problems which do occur are mainly as a result of spillage from the Karatoya; this appears to have caused extensive damage in the Planning Unit in every year since 1984. One of the reasons for spillage from the Karatoya may be that the flow in this river has increased as a result of spillage from the Teesta through breaches in the Teesta right embankment. The greatest flooding problems in this Planning Unit occur in the Middle Karatoya between Siraj and Mohimaganj.

The geometry of the main rivers which cross Planning Unit 6 were obtained from cross-section supplied by the SWMC during the first phase of the NWRS; these are shown in Table 4.7.

TABLE 4.7

Geometry of rivers in Planning Unit 6

River	Station	Depth (m)	Top width (m)	Slope (m/m)
Jamuneswari	Badarganj	5.2	80	0.00039
Karatoya	Siraj	3.8	300	0.00013
Bangali	Mohimaganj	5.0	180	0.00013

Flood frequencies for Badarganj and Mohimaganj were obtained by analysis of discharge observations. At Siraj the mean annual flood was estimated from analysis of the results of the NAM rainfall-runoff model results. Using these estimates of mean annual flood the regime theory was used to predict the regime width and depth of flow together with the regime slope.

In order to carry out these calculations a representative sediment diameter is required together with an estimate of the sediment concentration. The SWMC have collected suspended sediment and bed sediment samples from the Karatoya river; these have been analysed to obtained sediment concentrations and sediment particle size distributions.

The analysis of the suspended sediment samples showed a range of concentrations from less than 30 ppm to in excess of 500 ppm. For the regime analysis a representative sediment concentration of 300 ppm was selected. The particle size analysis of the Karatoya river bed samples revealed a d_{50} size of between 0.17 and 0.195 mm; a representative sediment size of 0.2 mm was used in the regime analysis.

The regime channel geometry, given by regime theory, for the locations in Table 4.7 are given in Table 4.8.

TABLE 4.8
Regime geometry of rivers in Planning Unit 6

River	Station	MAF (m^3/s)	Depth (m)	Top width (m)	Slope (m/m)
Jamuneswari	Badarganj	413	5.7	75	0.00016
Karatoya	Siraj	500	6.2	82	0.00016
Bangali	Mohimaganj	620	6.8	91	0.00015

From the regime analysis the following conclusions can be drawn,

- at Badarganj the top width and depth of the river is 'in regime'.

- at Siraj and Mohimaganj there will be a tendency for the river to become narrower and deeper.

- at Badarganj the regime slope is gentler than the observed slope. At this location the river is likely to become more meandering.

- at Siraj and Mohimaganj the regime slope is very similar to the observed slope which suggests that the Karatoya is 'in regime' at these locations.

Details of the morphology of the Ghagot and Alai rivers are given in Chapter 11. The impacts the developments proposed for the Gaibandha project area will have on the morphology of these rivers are described in Chapter 13.

Impact of existing developments

Karatoya FCD project : The Karatoya Flood Control Project is an on-going project situated on the left bank of the Karatoya river. As part of this project an embankment will be constructed along part of the left bank of the Karatoya. This embankment would result in an increase in the discharge in the river; the morphological response of the river would be an increase in both depth and width. If there is a significant increase in discharge the regime slope of the channel would decrease. If it is assumed that the valley slope does not change this would result in an increased tendency for meandering.

Impact of proposed developments

Proposed developments for other Planning Units would result in the sealing of the Teesta Right Embankment. Since part of the flow in the Karatoya originates from Teesta spills this would lead to a reduction in flow in the Karatoya. The morphological response to this change would be a tendency to become shallower, narrower and to flow a straighter course.

The main proposed development within this Planning Unit is full FCD on the left bank of the Karatoya from to Mohimaganj together with the Bangali Floodway. This development would reduce spills from the Karatoya and also improve drainage from the basins on the left bank of the river. An assessment of the morphological impact of the Bangali Floodway is given in Chapter 8.

4.5.7 Planning Unit 7 : Gaibandha

The river systems in this Planning Unit are modelled using the Gaibandha Improvement Project model as described in Section C of this report. The morphology of the present river system is described in Chapter 11. The impact that proposed developments will have on river morphology are described in Chapter 13.

4.5.8 Planning Unit 8 : Middle Bangali basin

The river systems in this Planning Unit are modelled using the sub-regional model. this modelling is described in Section B of this report.

The impact of sealing the BRE on the morphology of the Middle Bangali is described in Chapter 6. The impact that proposed developments will have on river morphology are described in Chapter 9.

4.5.9 Planning Unit 9 : Joypurhat

Present conditions

The main rivers flowing through this Planning Unit are the Little Jamuna, together with its left bank tributary the Tulsiganga, the Atrai and the Nagor. This Planning Unit contains the upper reaches of the Lower Atrai after this river has re-entered Bangladesh from the Indian enclave.

Serious and prolonged flooding does not occur in this Planning Unit. There is some crop damage as a result of spills from the Little Jamuna to the North of Badalgachi. An additional flooding problem occurs as a result of overland flow from India. The source of this water is probably spills from the Atrai in the Indian enclave.

The geometry of the main rivers which cross Planning Unit 9 were obtained from cross-section supplied by the SWMC during the first phase of the NWRS; these are shown in Table 4.9.

TABLE 4.9
Geometry of rivers in Planning Unit 9

River	Station	Depth (m)	Top width (m)	Slope (m/m)
Tulsiganga	Sonamukhi	6.0	60	0.00011
L. Jamuna	Badalgachhi	5.0	120	0.00015
L. Jamuna	Naogaon	8.0	80	0.00006
Atrai	Mohadevpur	7.8	160	0.00005

Flood frequencies for Naogaon and Mohadevpur were obtained by analysis of discharge observations. At Badalgachhi and Sonamukhi the mean annual flood was estimated from analysis of the results of the NAM rainfall-runoff model results. Using these estimates of mean annual flood the theory was used to predict the regime width and depth of flow together with the regime slope.

In order to carry out these calculations a representative sediment diameter is required together with an estimate of the sediment concentration. The SWMC have collected suspended sediment samples at Sonamukhi and bed sediment samples from the Little Jamuna river; these have been analysed to obtained sediment concentrations and sediment particle size distributions.

The analysis of the suspended sediment samples showed concentrations of less that 100 ppm; for the regime analysis a representative sediment concentration of 200 ppm was selected. The particle size analysis of the Little Jamuna river bed samples revealed a D_{50} size of 0.22 mm; a representative sediment size of 0.2 mm was used in the regime analysis.

The regime channel geometry, given by regime theory, for the locations in Table 4.9 are given in Table 4.10.

TABLE 4.10
Regime geometry of rivers in Planning Unit 9

River	Station	MAF (m^3/s)	Depth (m)	Top width (m)	Slope (m/m)
Tulsiganga	Sonamukhi	151	3.9	47	0.00016
L. Jamuna	Badalgachhi	286	5.1	63	0.00014
L. Jamuna	Naogaon	438	6.2	80	0.00013
Atrai	Mohadevpur	971	8.6	119	0.00011

From the regime analysis the following conclusions can be drawn,

- at Sonamukhi the Tulsiganga river will shown a tendency to be come shallower and narrower.
- the Little Jamuna at Badalgachhi will shown a tendency to become narrower.
- the Little Jamuna at Naogaon is likely to become shallower. The regime slope at this location is steeper than the observed slope; this indicates that the river is likely to become straighter.
- the Atrai at Mohadevpur shows a tendency to become deeper and shallower. the regime slope at this location is steeper than the observed slope; this indicates that the river is likely to become straighter.

Impact of existing development

Tulshiganga Project : This project involved construction of embankments along parts of the Little Jamuna and Tulshiganga rivers. These embankments prevented spills from the rivers. These embankments, by preventing spills, would result in an increase in the discharge in the rivers; the morphological response of the river would be an increase in both depth and width. If there is a significant increase in discharge the regime slope of the channel would decrease. If it is a assumed that the valley slope does not change this would result in an increased tendency for meandering.

Tulshiganga Left embankment project : After the completion of the right embankment of the Tulshiganga this project was initiated to construct on embankment on the left bank to prevent spills. This embankment will have a similar impact on the river morphology as the right embankment of the Tulshiganga.

Impact of proposed developments

Serious and prolonged flooding does not occur in this Planning Unit; no major developments are proposed.

On the right bank of the Little Jamuna upstream of Badalgachhi crop damage is relatively severe; further embanking in this area may be necessary. Any embankments could result in an increase in both depth and width together with an increased tendency for meandering.

4.5.10 Barind Tract

Present conditions

This Planning Unit consists mainly of elevated land. There are no major rivers which flow through the Planning Unit. The Planning Unit is bounded in the South by the Ganges, in the West by the Mohananda and in the East by the Atrai and the Shib. The northern boundary of the area is formed by the Indian border.

Since this area consists of elevated land there are no flooding problems as a whole. The problems are flooding of a strip along the Shib river and drainage congestion on the north side of Chalan Beel Polder D, in the eastern area of the unit. these problems are because drainage channels were interrupted by the western embankment of Chalan Beel Polder D.

Impact of existing developments

The drainage of flood waters across Polder D and the flooding from the Shib river in the eastern part of the Barind Tract are being considered in the sub-regional model. the present river morphology of the area is described in Chapter 7; any impacts that proposed developments will have on river morphology are described in Chapter 9.

Impact of proposed developments

The proposed developments in this Planning Unit relate to irrigation rather than flood protection and drainage; these projects are unlikely to have an impact on river morphology.

4.5.11 Planning Unit 11 : Mohananda Basin

Present conditions

The north and western boundary of the planning unit is formed by the Indian border. The eastern boundary is formed by the elevated land of the Barind Tract. The Ganges (Padma) forms the southern boundary of this planning unit and the Mohananda is the principal river which bisects the planning unit in a north-western direction. The other important river is the Pagla which meets the Mohananda river near Mohanpur. The Punarbhaba river enters the planning unit in the north-west corner and joins the Mohananda river. All the rivers flowing through this unit originate from outside Bangladesh and bring most of their flows from there.

Beels areas on the right bank of the Mohananda river suffer from flooding mainly due to spillage from the Mohananda and Pagla rivers are mainly responsible for this flooding. Runoff from higher land is the main source of this spillage water. The flood water levels of the Mohananda in the lower reaches are strongly influenced by the backwater effect of the Ganges. Drainage congestion in these areas is a problem.

The geometry of the Mohananda river at Godagari was obtained from a cross-section supplied by the SWMC during the first phase of the NWRS; this geometry is shown in Table 4.11.

TABLE 4.11
Geometry of rivers in Planning Unit 11

River	Station	Depth (m)	Top width (m)	Slope (m/m)
Mohananda	Godagari	16	300	0.00014

Flood frequencies at Godagari were obtained by analysis of discharge observations. Using this estimate of mean annual flood the regime theory was used to predict the regime width and depth of flow together with the regime slope.

There are no observations of sediment concentration or sediment size for the Mohanda river. A sediment concentration of 200 ppm and a representative sediment size of 0.2 mm were assumed for the regime analysis.

The regime channel geometry, given by regime theory, for Godagari on the Mohananda river is given in Table 4.12.

TABLE 4.12
Regime geometry of rivers in Planning Unit 11

River	Station	Depth (m)	Top width (m)	Slope (m/m)
Mohananda	Godagari	16	254	0.00078

From the regime analysis the following conclusions can be drawn,

- the Mohananda river will shown a tendency to become narrower.
- the regime slope of the Mohananda river at Godagari is gentler than the observed slope; this indicates that the river will show an increased tendency to meander.

Impact of existing development

The existing developments in this planning unit consist of a number of small FCD/drainage schemes. Each of these schemes consists of flood embankments together with drainage improvements. The results of these schemes have been the embanking of considerable reaches of both the Mohananda and Pagla rivers. These embankments, by preventing spills, would result in an increase in the discharge in the rivers; the morphological response of the river would be an increase in both depth and width.

If there is a significant increase in discharge the regime slope of the channel would decrease. If it is assumed that the valley slope does not change this would result in an increased tendency for meandering.

Regime analysis suggests that the Mohananda has a tendency to become more meandering. This combined with the impact of embanking which will further increase the tendency to meander could result in erosion problems on the flood embankments.

Rises in water level in the Mohananda which could result from embanking may increase the problems of drainage congestion further.

Impact of proposed development

The proposed developments for this area consist of either full or partial embankments on the right bank of the Mohananda to prevent spills into the beel areas. These embankments, by preventing spills, would result in an increase in the discharge in the rivers; the morphological response of the river would be an increase in both depth and width. If there is a significant increase in discharge the regime slope of the channel would decrease. If it is assumed that the valley slope does not change this would result in an increased tendency for meandering.

Regime analysis suggests that the Mohananda has a tendency to become more meandering. this combined with the impact of embanking which will further increase the tendency to meander could result in erosion problems on the flood embankments.

Rises in water level in the Mohananda which could result from embanking may increase the problems of drainage congestion further.

4.5.12 Planning Unit 12 : Lower Atrai Left bank

The river systems in this Planning Unit are modelled using the sub-regional model. this modelling is described in Section B of this report.

The present river morphology in this planning unit is described in Chapter 7. The impact that proposed developments will have on river morphology are described in Chapter 9.

4.5.13 Planning Unit 13 : Lower Atrai right bank

The river systems in this Planning Unit are modelled using the sub-regional model. this modelling is described Section B of this report.

The present river morphology in this planning unit is described in Chapter 7. the impact that proposed developments will have on river morphology are described in Chapter 9.

4.5.14 Planning Unit 14 : Lower Bangali basin

The river systems in this Planning Unit are modelled using the sub-regional model. This modelling is described in Section B of this report.

The present river morphology in this planning unit together with the impact that sealing the BRE would have on morphology, is described in Chapter 6. the impact that proposed developments will have on river morphology are described in Chapter 9.

4.5.15 Planning Unit 15 : Pabna

Present conditions

This planning unit is bounded on two sides by major rivers, the jamuna and Padma. the northern boundary of the unit is formed by the Baral. The internal drainage of the unit is from west to east and comprises the Chiknai, Ichamati and Atrai rivers.

Flooding in this unit has been reduced significantly by the construction of the main embankments around the area. Currently flooding is experienced through spillage of water from the River Ganges. Drainage congestion is also experienced because of the long lasting high water levels in the major rivers; this problem is partly alleviated by pumped drainage at some locations.

Impact of existing development

The present developments have effectively eliminated the flooding problems in this unit by reducing the spills from the major rivers. This will have resulted in the reduction in discharge in the internal rivers. The morphological response of the rivers to this will be a tendency to become shallower and narrower, and to follow a straighter course.

Impact of proposed developments

The proposed developments for this unit involve the completion of flood embankments on the northern and western sides. this will lead to a further decrease in the discharge of the internal rivers. The morphological response of the rivers to this will be a tendency to become shallower and narrower, and to follow a straighter course.

Complete embankment of the unit could further increase the problem of drainage congestion due to high water levels in the major rivers which bound the unit.

SECTION C

SUB-REGIONAL MODEL

CHAPTER 5
DEVELOPMENT AND CALIBRATION OF THE SUB-REGIONAL MODEL

5.1 Introduction

This Chapter covers the development and calibration of a 'sub-regional model' of the North West Region. The model covers the Lower Atrai and Middle/Lower Bangâli river basins, see Figure 2.2. Initial development of the sub-regional model was undertaken at the SWMC jointly by SWMC and FAP-2 modellers. Final development and calibration was undertaken by the FAP-2 modelling team.

The model was calibrated for the 1990 and 1991 flood seasons. Much greater emphasis was placed on the latter flood season since this was the year with the best topographic and hydrologic data; most was also known about the flooding regime in this year together with the location of breaches and cuts. In a hydrological context 1991 was a reasonable high flood year. Additional verification of the model was carried out by simulating the five year period between 1985-89.

Since the model was calibrated against flood season water levels and flow rates it can only be used with confidence to study developments under these conditions. If a study which required the investigation of lower water levels and flow rates were required the suitability of the developed model to simulate these conditions must be reassessed.

Following the calibration and verification of the model it was used in the 25 year simulation run for a future 'without' project condition; this simulation is reported in Chapter 7.

5.2 Sub-regional model development

5.2.1 Development at the SWMC

The NWRM modelling group at the SWMC began work on their **full** sub-models of the North West region following completion of the **pilot** model calibration in late 1991. As with the pilot models their philosophy was to develop the models as a number of sub-models of the region. Once calibration of the sub-models is achieved they will then be inter-connected to produce a model of the entire north west region and final calibration undertaken on this combined model.

To support the upgrade of the models from **pilot** to **full** model stages there has been additional cross-sectional surveys and, as in previous years, additional collection of hydrometric data to supplement the BWDB data collection programmes. The additional cross-sectional information was used to increase the resolution of the models and to include river branches which were omitted from the pilot model set-up.

The SWMC have been working on the **full** models since late 1991. In order to maintain close links and to assist in the overall development of the models FAP-2 provided a team of modellers to work alongside the SWMC team. Joint field visits were carried out with SWMC staff and FAP-2 hydraulic modellers in order to increase understanding of flooding in the North West region. In addition FAP-2 also provided a computer system to supplement the SWMC computer network.

By mid-March 1992 initial calibration of sub-models which covered the following areas had been carried out:

- Lower Atrai basin (the Atrai sub-model)
- Middle and Lower Bangali basin (the Link sub-model)

5.2.2 Further developments by FAP-2 modelling team

Throughout the initial development of the North West Regional Model the SWMC team have been using the Unix based version of MIKE11. On the NWRS, however, it was selected to use the DOS version as this has been fully developed and well tried and tested on many applications.

Because of time constraints within the North West Regional Study the FAP-2 modelling team returned to the FAP-2 offices in mid-March 1992 to continue calibration of the sub-regional model.

The developments by the FAP-2 modelling team consisted of combining the Atrai and Link sub-models into a sub-regional model and then re-calibrating this model.

5.3 Sub-regional model set-up

5.3.1 The sub-regional model area

The sub-regional model covers the Lower Atrai and Middle/Lower Bangali river basins. The upper boundary on the Bangali was taken as Mohimaganj and along a line between Mohadevpur and Palgacha in the Lower Atrai basin. This represents a combination of the Atrai and Link sub-models developed at the SWMC. Figure 2.2 illustrates the area of the sub-regional model.

5.3.2 The model set-up

Figure 5.1 gives a broad indication of the drainage patterns within the sub-regional model area. The model was developed specifically to reproduce the main features of these drainage paths and a corresponding schematic of the river system represented in the sub-regional model is given in Figure 5.2. The important new features of this model, most of which were not incorporated into the pilot model of the North West region, were as follows:

- major breaches were evident in the BRE during the 1991 flood season. FAP-1 identified six such breaches in the reach between Mohimaganj and the outfall of the Hurasagar. The two largest breaches are in the vicinity of Mathurapara where the Bangali river is less than 3 km from the breach in the BRE. The other large breach is to the South of Sariakandi at Kazipur. The six breaches identified by FAP-1 were incorporated into the sub-regional model. The breach channels were either those surveyed by FAP-1 or were based on the general topography of the area. Broad crested weirs were used to represent the breaches; advice on the detailed definition of these was obtained from FAP-1 hydraulic modellers.

- field surveys indicated that large areas of the Lower Bangali basin flood as a result of the breaches in the BRE. In order to simulate this a number of artificial channels were included in the sub-regional model to allow East - West flow between the rivers of the Lower Bangali basin (Ichamati - Bangali - Durgadah).

- breaches / public cuts occur in the western embankment of Chalan Beel Polder D in order to relieve flooding in the Shib which occurs as a result of runoff from the Barind Tract. Water flows across Chalan Beel Polder D and enters the Fakirni at the regulator site. This flow route was represented in the model by a channel whose geometry was based on the topography of Chalan Beel Polder D. The breaches at either end of this channel were represented by broad crested weirs.

- the embankment of Chalan Beel Polder C breaches a short distance downstream of Jotebazar (the Fakirni bifurcation). Public cuts are made further downstream in the embankment of Chalan Beel Polder C in order to relieve the flooding which results from this breach. These flow routes were represented in the model by channels whose geometry was based on the topography of Chalan Beel Polder C. The breaches at the end of these channels were represented by broad crested weirs.

- the Naogaon Polder scheme is not yet complete. It is open near the confluence on the Atrai and the Little Jamuna; at this location a number of regulators are being constructed. The Naogaon Polder was represented as a flood cell which was connected to the Atrai at the Atrai - Little Jamuna confluence. A broad crested weir was used to control flow into and out of the Naogaon Polder flood cell.

- field surveys indicate that, under flood conditions, flow may occur from the Little Jamuna to the Nagor across Bogra Polder 2. An artificial channel, containing a broad crested weir to control the flow, was introduced to represent this flow route.

- the Southern embankment of Bogra Polder 2 is breached on the northern bank of the Atrai; this allows a flow route from the Atrai to the Nagor. An artificial channel, containing a broad crested weir to control the flow, was introduced to represent this flow route.

- Bogra Polder 2 drains to a point on the Nagor a short distance upstream of the confluence of this river with the Atrai. Field surveys indicate that a breach occurs at this location every year; a broad crested weir was introduced to represent this breach. The artificial channels from the Little Jamuna and the Atrai were also linked to this breach.

- opposite the aforementioned breach in the right embankment of the Nagor a breach occurs which allows drainage across Bogra Polder 3 into the Bhadai river system. An artificial channel, containing a broad crested weir to control the flow, was introduced to represent this flow route.

- the drainage of Bogra Polder 3 and Bogra Polder 4 through the Bhadai river system is complex with a number of drainage channels linking the Beel area to the Atrai. A number of channels linking the Bhadai to the Atrai were introduced to represent these drainage channels. Field surveys indicated that drainage of this Beel area can occur directly to the Atrai in the vicinity of Astomonisha. A channel was introduced to represent this flow route.

- during the flood season a head difference occurs across the Taras embankment which separates the Lower Atrai basin from the Lower Bangali basin. The Taras embankment is breached to equilibrate the flood levels. An artificial channel, containing a broad crested weir to represent the breach, was introduced to represent this flow route and hence allow flow from the Lower Atrai basin into the Lower Bangali basin.

5.3.3 Incorporation of flood plains

Flood plains were not incorporated into the pilot model of the North West region; cross sections extended only marginally past bank top level. In the sub-regional model flood plains were attached

to the river cross-sections at locations where embankments which prevented spillage onto the flood plain were not present. The topography of the flood plains were based on the MPO 1 sq. km. database of levels.

In a number of cases, the resulting flood plain area-elevation curve did not compare well with the cross-section, in that it was above or below the cross section elevation. Following the methodology developed by FAP-1 the cross section elevation was changed at some selected locations along the Bangali to agree with the flood plain elevations. This was done since, in general, greater confidence can be placed in the general topography levels than the datums for river cross sections.

The roughness of the flood plain was taken to be twenty times that in the river channels to which the flood plain was attached.

5.3.4 Model boundaries

There are 17 external boundaries in the sub-regional model; the schematic location of the primary boundary locations can be seen in Figure 5.2.

At ungauged discharge boundaries and at the head of minor channels and upland drainage routes the NAM model were used to provide the inflows into the sub-regional model.

5.4 Model calibration

5.4.1 Methodology

Having set up the basic structure of the model, there follows a process of proving that it is adequate to reproduce the system which it is intended to represent. This process is two stage, one of calibration and thence verification. For the sub-regional model calibration was carried out for the 1991 flood season and verification for the 1990 flood season. Further model verification was carried out for the period from 1985-89. In the calibration exercise, the model is adjusted such that a given set of observed values is reproduced by the model. The verification of the model follows by checking its performance against an additional set of observed values which were not included in the original data set used for calibration. It is often found that the deviations of the model results for verification runs are greater than those during calibration. It is difficult to define objective criteria for assessing the quality of a model calibration. Often the modeller must rely on his experience and subjective judgement to decide whether or not to halt the calibration. A further constraint on model calibration is the time scale of the project and the requirement of model results by other disciplines within the study. There has been no work done in the NWRS in the definition of objective criteria for model calibration adequacy, purely subjective judgement has dictated the progress of the modelling.

Model calibration was carried out for the monsoon period; this is the period of greatest significance for the NWRS. The objective of calibration was to minimise difference between the modelled and observed data during this period. It is clear from the model verification that if the study were to be concerned with water levels and discharges during the dry season, much additional work would be required to give satisfactory calibration during these periods.

As described in Section 5.2 the sub-regional model was initially calibrated as two sub-models; the Lower Atrai model and the Link model which covered the Lower and Middle Bangali basins. This initial calibration was carried out at the SWMC. This was done in order to minimise model run times and thus allow the maximum number of calibration runs to be carried out. Once the initial calibration

had been carried out as far as was possible the two sub-models were combined; final calibration was carried out on the full sub-regional model.

The final model set-up which is described in Section 5.3 was developed as part of the calibration process. In particular a number of artificial channels were added to allow flow across flood plains between adjacent river catchments. As far as was possible the location of these channels was based of information collected during field visits. Some of the channels were added in order to approve the fit at particular calibration points.

A number of weirs were included in the model set-up; these represented breaches or cuts in embankments and also road culverts. Weirs were also used to control flows in the artificial channels which were introduced into the model set-up. As far as was possible the elevation of weir crests and the width of weirs was based on field observations. During model calibration the crest elevation and width of some weirs was adjusted in order to improve agreement between simulated and observed data.

The other main parameter which was adjusted as part of the calibration process was the roughness in the river channels. In all cases physically reasonable values of roughness coefficients were used. In some cases these were either higher or lower than values which would normally be expected for the rivers being simulated. This was probably because they were simulating the effect of features which it was not possible to explicitly represent in a one dimensional hydrodynamic model such as MIKE11.

5.4.2 Calibration results

Results of the model calibration are presented in this section; these results are for the 1991 monsoon season. The results for 1990 showed similar features to those for 1991. Minor adjustments were made to the model based on the results for 1990. Given this situation the calibration data set was effectively extended to include both 1991 and 1990; 1990 could not really be referred to as a verification year since data for this year was used, at least partially, during the calibration. The period from 1985 to 1989 was used for model verification; the results of this is described in Section 5.5.

Mohadevpur (Figure 5.3) : Mohadevpur is on the Atrai river, it is a discharge boundary station for the sub-regional model. A comparison between the simulated and observed water levels at Mohadevpur in shown in Figure 5.3. The agreement between simulated and observed water levels is good. The model slightly over estimates the majority of the water level peaks. The exception to this is the highest peak which occurs in September; this peak is matched extremely well. Following the monsoon season water level peaks the rate of recession simulated by the model is slightly slower than that observed.

Jotebazar (Figure 5.4) : Jotebazar is on the Atrai river at the point where the Fakirni spills to the South. A comparison between the simulated and observed water levels at Jotebazar in shown in Figure 5.4. The results at Jotebazar show similar features to those at Mohadevpur, however, the difference between the simulated and observed water levels are more pronounced. The over estimation of the water level peaks is greater at Jotebazar; once again the exception to this is the September peak which is matched extremely well. The simulated recession following the monsoon peak water levels is considerably slower than that observed.

Atrai railway bridge (Figure 5.5 and 5.27) : Atrai railway bridge is on the Atrai river between the confluence with the Little Jamuna and the confluence with the Nagor. A comparison between the simulated and observed water levels at Atrai railway bridge is shown in Figure 5.5. In general the peak water levels are simulated well; some of the peaks are slightly over-estimated. Once again the simulated water level recession following the monsoon season peak is slower than that observed. A comparison between the simulated and observed discharges at Atrai railway bridge is shown in Figure 5.27. The agreement between the two discharges hydrographs is reasonable. The simulated discharges for the September peak flow are high. The post monsoon discharge recession is fitted well.

Singra railway (Figure 5.6 and 5.28) : Singra railway bridge is located on the Atrai river a short distance downstream of the confluence of the Kharsati with the Atrai. At its upstream end the Kharsati is linked to the Nagor; the Kharsati only flows during the monsoon season. A comparison between the simulated and observed water levels at Singra railway bridge is shown in Figure 5.6. The model generates a good simulation of the observed hydrograph; the water level peaks are matched well. The simulated post-monsoon water level recession is slower than that observed. A comparison between the simulated and observed discharges at Singra railway bridge is shown in Figure 5.28. The model over estimates the peak flows in July and September; it also over estimates the flow during August when there is a trough in the observed flows. At other times there is a good match between the simulated and observed discharge hydrographs. The post monsoon discharge recession is fitted well.

Chankchoir (Figure 5.7) : Chankchoir is located on the Atrai at the point where the Nanjakuja joins the Atrai. A comparison between the simulated and observed water level hydrographs at Chankchoir is shown in Figure 5.7. The model under estimates the water level by approximately 0.5 m throughout the flood season. The simulated post monsoon water level recession is slower than that observed.

Astomonisha (Figure 5.8) : Astomonisha is on the Atrai river at the point where it splits into the Atrai and the Baral. A comparison between the simulated and observed water level hydrographs at Astomonisha is shown in Figure 5.8. The pattern at Astomonisha is very similar to that at Chankchoir; the model tends to under estimate the water levels throughout the flood season. There are no water level observations during the post monsoon recession for comparison with the model results.

Gumani railway bridge (Figure 5.9) : Gumani railway bridge is located on the Atrai river between the point where the Baral spills and rejoins the Atrai. Figure 5.9 shows a comparison between the observed and simulated water level hydrographs at Gumani railway bridge. The model slightly under estimates the water levels during the flood season. The agreement between the model water levels and those observed is better than at either Chankchoir or Astomonisha. Once again the simulated water level recession is slower than that observed.

Baral railway bridge (Figure 5.10 and 5.29) : Baral railway bridge is on the Baral river between where it spills from the Atrai and where it rejoins. A comparison between the simulated and observed water levels at Baral railway bridge is shown in Figure 5.10. The match between the two hydrographs is good. The model slightly under estimates the September peak water level. The post monsoon water level recession is slightly slower than that observed. Figure 5.29 shows a comparison between the simulated and observed discharges at Baral railway bridge. The model over estimates the July and September peak discharges; at these times the observed discharges look suspect. The model matches the September discharge rise extremely well; it also produces a reasonable simulated of the post monsoon discharge recession.

Dohokladanga (Figure 5.11) : Dohokladanga is on the Atrai river a short distance downstream of where the Baral joins. Figure 5.11 presents a comparison between the simulated and observed water levels at Dohokladanga. The model reproduces the observed water levels extremely well. The simulated post monsoon water level recession is slightly slower than that observed.

Nowhata (Figure 5.12 and 5.30) : Nowhata is located on the Shib river at the point where its flow direction changes from north-south to west-east. Figure 5.12 shows a comparison between the simulated and observed water level hydrographs at Nowhata. The model reproduces the shape of the observed water level hydrograph reasonable well but the peaks water levels are under estimated. The simulated post monsoon water level recession is slower than that observed.

A comparison of the observed and simulated discharges at Nowhata is presented in Figure 5.30. Until mid-September the model generates a reasonable match to the observed discharges. The model over estimates the early October peak discharge; it then predicts higher than observed discharges for the remainder of the calibration period. The rate of discharge recession is matched well.

Bagmara (Figure 5.13) : Bagmara is on the Shib river at the points where the Fakirni joins it. The Fakirni spills from the Atrai at Jotebazar. Figure 5.13 presents a comparison between the observed and simulated water level hydrographs at Bagmara. The model produces a good simulation of the observed hydrograph. The simulated post monsoon water level recession is slower than that observed.

Naldanga railway bridge (Figure 5.14 and 5.31) : Naldanga railway bridge is located on the Shib river between Bagmara and the confluence of the Shib with the Atrai. A comparison between the observed and simulated water level hydrographs at Naldanga railway bridge is presented in Figure 5.14. The pattern is very similar to that at Bagmara. The model produces a good simulation of the observed water levels but the rate of recession is slower than that observed. Figure 5.31 shows a comparison between the observed and simulated discharges at Naldanga railway bridge. The match is reasonable. The model over estimates the August and September peak flows.

Naogaon (Figure 5.15) : Naogaon is located on the Little Jamuna river. It is a discharge boundary station for the sub-regional model. Figure 5.15 presents the observed and simulated water level hydrographs at Naogaon. The model produces a good fit to the observed water levels. At certain times the model produces a slight over estimate of the observed water levels. The simulated post monsoon water level recession is a little slower than that observed.

Talora (Figure 5.16) : Talora is located on the Nagor river. It is a discharge boundary station for the sub-regional model. Figure 5.16 presents a comparison between the observed and simulated water level hydrographs at Talora. The model reproduces the shape of the observed hydrograph well. The simulated variations in water level are not as great as those observed; the model slightly under estimated peak water levels and over estimates lowest water levels during the flood season.

Malonchi (Figure 5.17) : Malonchi is located on the Nanjakuja river. It is a discharge boundary station for the sub-regional model. A comparison between the simulated and observed water levels at Malonchi is presented in Figure 5.17. There is good agreement between the two hydrographs. The model over estimates the September peak water level and the rate of post monsoon water level recession is slower than that observed.

Halsa (Figure 5.18) : Halsa is located on the Nanjakuja river between Malonchi and the confluence of the Nanjakuja with the Atrai at Chankchoir. A comparison between the observed and simulated water levels at Halsa is presented in Figure 5.18. The model matches the pattern of water level

variations well but under estimates the peak water levels by approximately 0.5 m. The simulated rate of post monsoon water level recession is slower than that observed.

Mohimaganj (Figure 5.19) : Mohimaganj is on the Bangali river. It is discharge boundary station for the sub-regional model. Figure 5.19 presents a comparison of observed and simulated water level hydrographs at Mohimaganj. The model reproduces the pattern of observed water level variations reasonable. The model over estimates some peak water levels and under estimates other peak water levels. The simulated post monsoon water level recession is slightly quicker than that observed.

Simulbari (Figure 5.20 and 5.32) : Simulbari is on the Bangali river a short distance downstream of Mohimaganj. A comparison between observed and simulated water levels at Simulbari is presented in Figure 5.20. At this station the differences between the observed and simulated hydrographs are very similar to those at Mohimaganj. Figure 5.32 presents a comparison between the observed and simulated discharges at Simulbari. The model matches the lower flows well but over estimates the peak discharges. The post monsoon discharge recession is matched well.

Sariakandi (Figure 5.21) : Sariakandi is on the Bangali river downstream of Simulbari and upstream of the Ichamati spill. Figure 5.21 compares the observed and simulated water levels at Sariakandi. The fit between the two hydrographs is good. The model under estimates the September peak water level. The simulated post monsoon water level recession is quicker than that observed.

Khanpur (Figure 5.22 and 5.33) : Khanpur is located on the Bangali river a short distance downstream of where the Karatoya joins the Bangali. A comparison of the observed and simulated water levels at Khanpur is presented in Figure 5.22. The model matches the lower flows well but under estimates the peak discharges. The post monsoon discharge recession is well matched. Figure 5.33 shows a comparison of the observed and simulated discharges at Khanpur. In general the agreement between the two discharge hydrographs is good. The model over estimates the flow in early June. It matches the July peak discharge perfectly. The model over estimates the lower flows in August and September and under estimates the September peak flow.

Raiganj (Figure 5.23) : Raiganj is located on the Bangali at the point where the Durgadah spills from the Bangali. Figure 5.23 compares the observed and simulated water levels at Raiganj. The model under estimates the water levels; this is usually by approximately 1 m but the model under estimates the some peak water levels by 2 m. This difference between observed and simulated water levels may indicate a datum error at the Raiganj gauging station.

Nalkasengati (Figure 5.24) : Nalkasengati is located on the Bangali river a short distance downstream of where the Ichamati rejoins the Bangali. Figure 5.24 compares the observed and simulated water levels at Nalkasengati. Up to late July the model slightly under estimates the observed water levels. The model under estimates the August, September and October peak water levels by approximately 1 m.

Ullapara (Figure 5.25 and 5.34) : Ullapara is located on the Bangali between Nalkasengati gauging station and the confluence of the Bangali with the Atrai. A comparison of the observed and simulated water levels at Ullapara is presented in Figure 5.25. The fit between the two hydrographs is good. The model slightly under estimates the peak water levels. Figure 5.34 compares the observed and simulated discharges at Ullapara. The model tends to under estimate the flow throughout the flood season. The model reproduces the post monsoon discharge recession well.

Nangolar railway bridge (Figure 5.26) : Nangolar railway bridge is located on the Durgadah river a short distance upstream of the confluence of the Durgadah (Gohala) with the Atrai. Figure 5.26 compares the observed and simulated discharges at Nangolar railway bridge. The model simulates the pattern of the observed discharge variations well but it over estimates the peak flows.

Baghabari (Figure 5.35) : For modelling purposes Baghabari water levels form the downstream boundary of the model. A comparison of the observed and simulated discharges at Baghabari is presented in Figure 5.35. The model produces a reasonable simulation of both the pattern and magnitude of the observed discharges. This indicates that the overall water balance and flow volumes which are applied at the boundary nodes and the NAM rainfall-runoff contributions are reasonable. The model also reproduces the some of the observed reverse flows which occur at Baghabari.

5.4.3 Summary of model calibration results

Taken as a whole the agreement between the simulated and observed data is good. The model calibration has concentrated on fitting observed water levels. This is reflected in the fact that the agreement between the observed and simulated water level hydrographs is, in general, better than the agreement between the observed and simulated discharges. The agreement between the simulated and observed discharge are sufficiently good to indicate that the split of flows between the different rivers in the sub-regional model area is simulated reasonably in the model.

The greatest discrepancy between the simulated and observed water levels occurs during the post monsoon water level recession. In the Atrai basin the modelled rate of recession is slower than that observed whilst in the Bangali system the simulated rate of recession is slightly quicker than that observed. A reason for these differences may be the flow patterns change during the post monsoon period as a result of breaches or public cuts which are not represented in the model. The model set-up has been assumed to be the same at all times; it does not take account of dynamic changes due to new breaches or public cuts.

The calibration results are, in general, within the guidelines of model accuracies given by the Flood Action Plan Model Coordinating Committee (FAPMCC) for pre-feasibility modelling studies. These guidelines are:

- peak water levels are matched to within 0.5 m.
- peak discharges are matched to with 25 %.

The calibration results therefore give confidence that the model is suitable for undertaking simulations to investigate the impact of proposed developments in the area covered by the sub-regional model.

5.5 Comparison with 1985-89 observations

Because of temporal changes in flow routes which are not represented in the model no direct comparison should be made between the model results and observations for the period 1985-89. Running the model for this period does allow for some verification of the models performance. It is known that public cuts during high flood years generally occur at similar locations from year to year. Essentially, the cuts are made at locations where there is drainage congestion or a marked discrepancy between internal and external water levels. Typical locations are the right bank of the Atrai, at the head of Chalan Beel Polder C, the left and right embankments of the Nagor river and the Taras embankment on the western limit of the SIRDP project. In many cases these are only

repaired temporarily and are breached or cut once again the following year. The drainage patterns that this imposes on the hydraulic regime is therefore similar from one year to the next although the magnitudes of the spills through these openings will vary.

Comparisons between modelled and observed water levels and discharges at key locations for the period 1985-89 showed an acceptable correlation with the observed results. This gave further confidence that the model is suitable for undertaking simulations for the full 25 year period from 1964-89.

Figure 5.1
Drainage Patterns

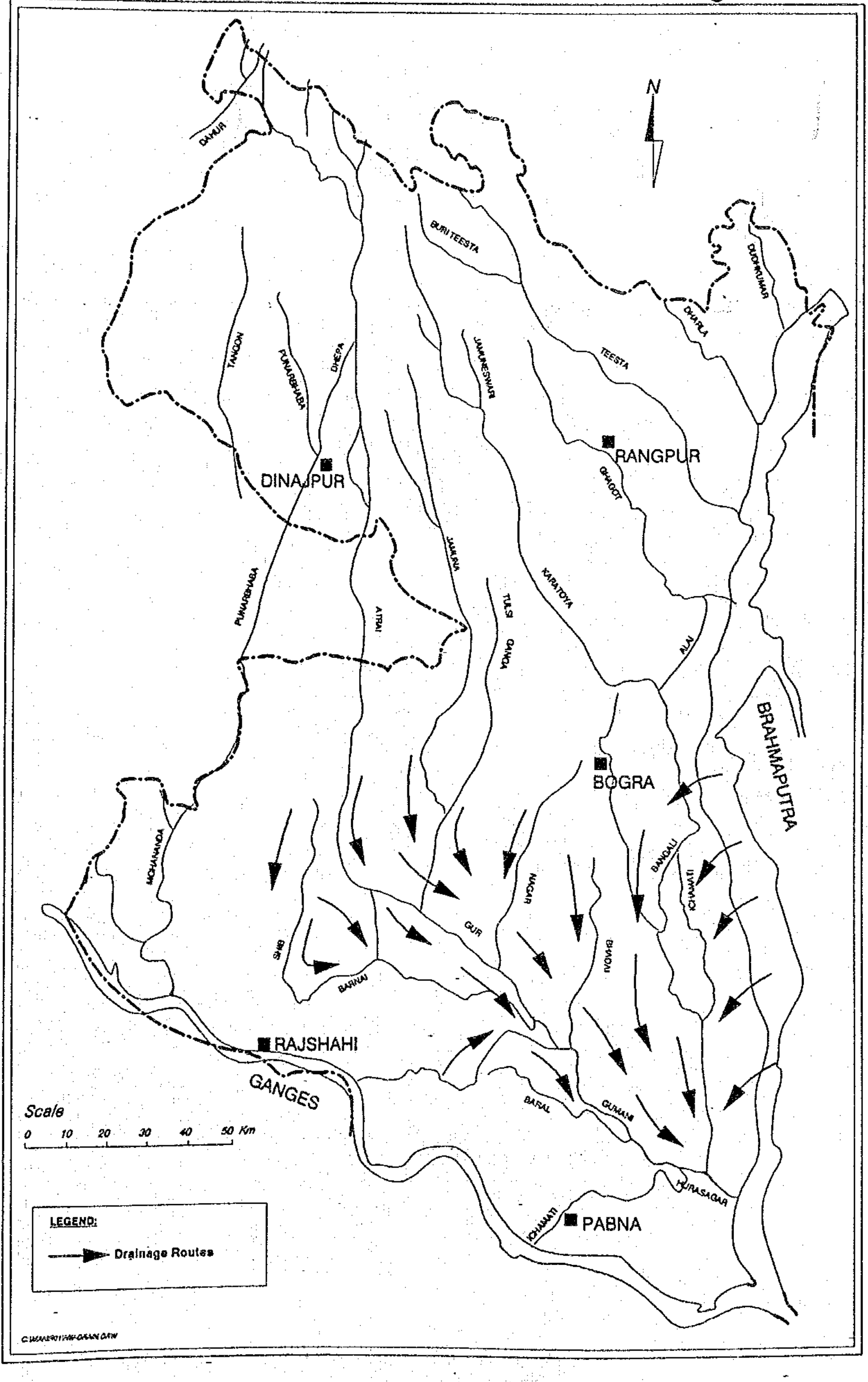
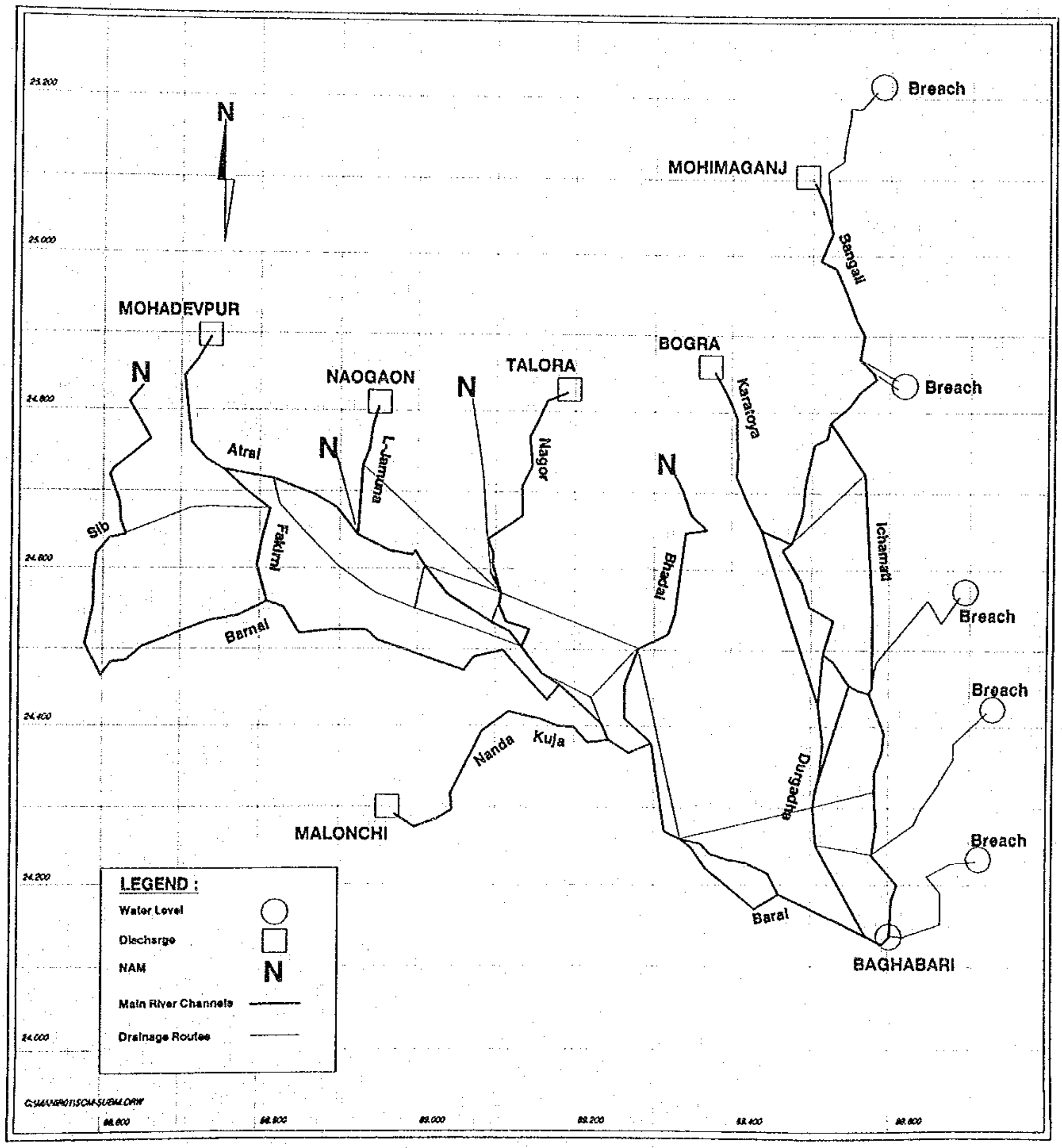


Figure : 5.2

Schematic of Sub-Regional Model



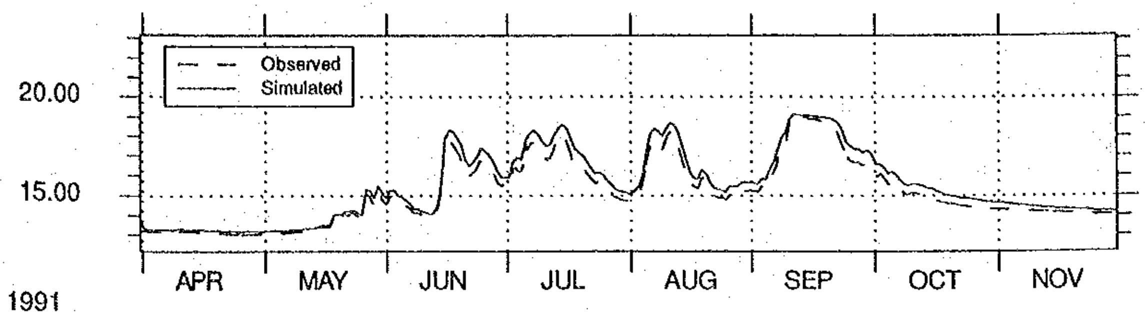


Figure 5.3 **Mohadevpur (wl)**

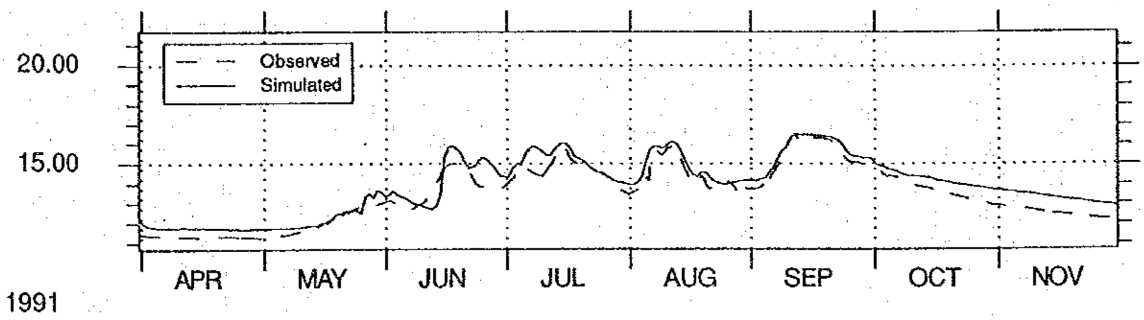


Figure 5.4 **Jotebazar(wl)**

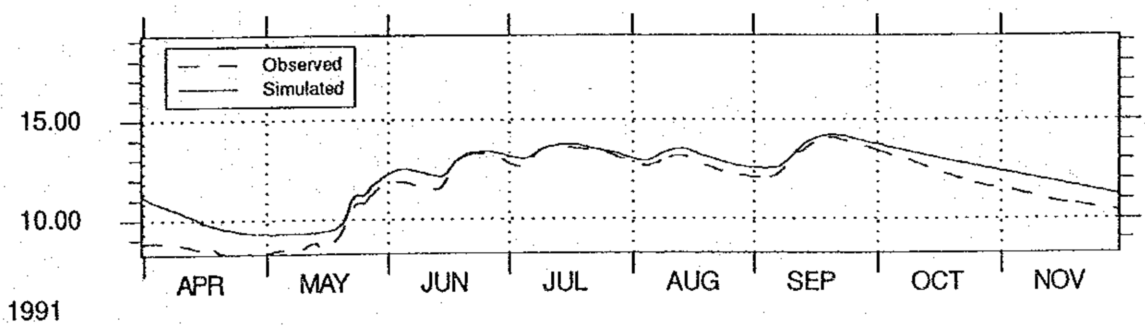


Figure 5.5 **Atrai RB(wl)**

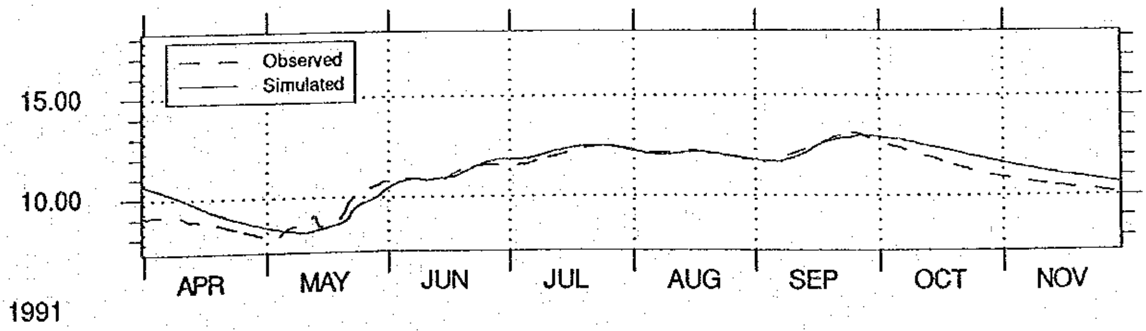


Figure 5.6 **Singra (wl)**

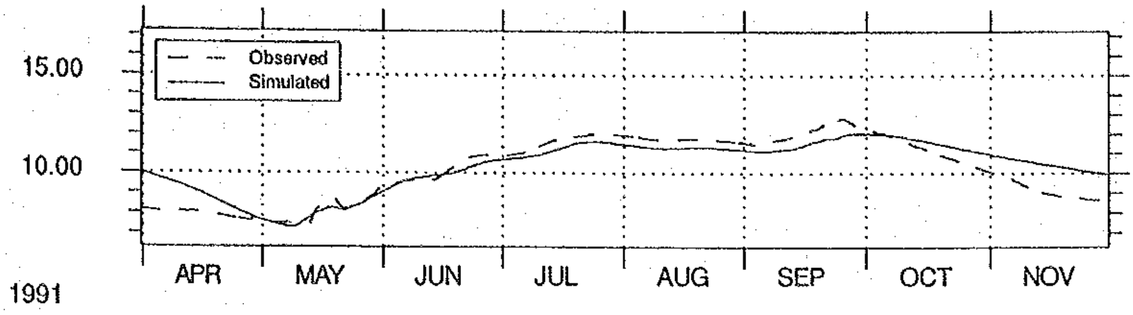


Figure 5.7 **Chankchoir (wl)**

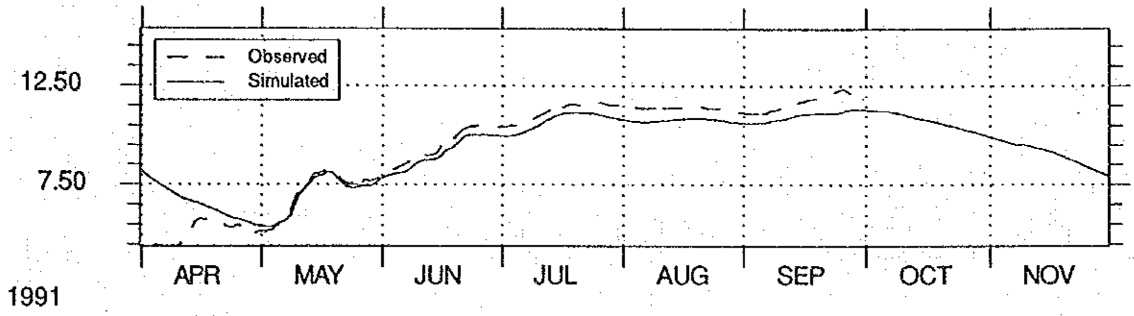


Figure 5.8 **Astomonisha (wl)**

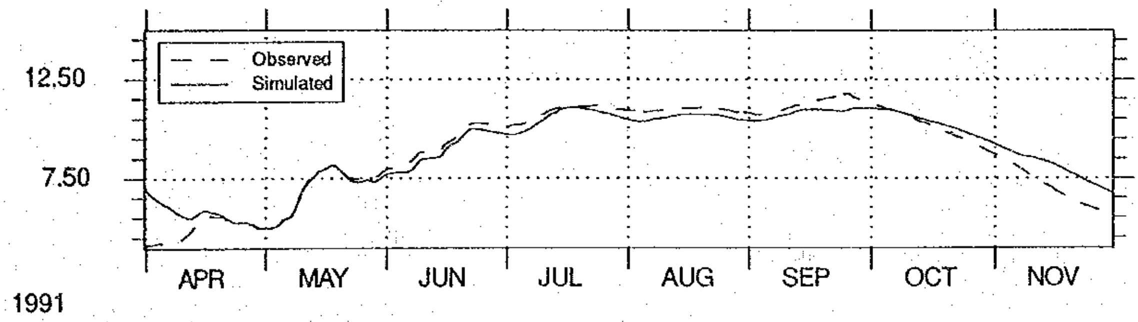


Figure 5.9 **Gumani RB (wl)**

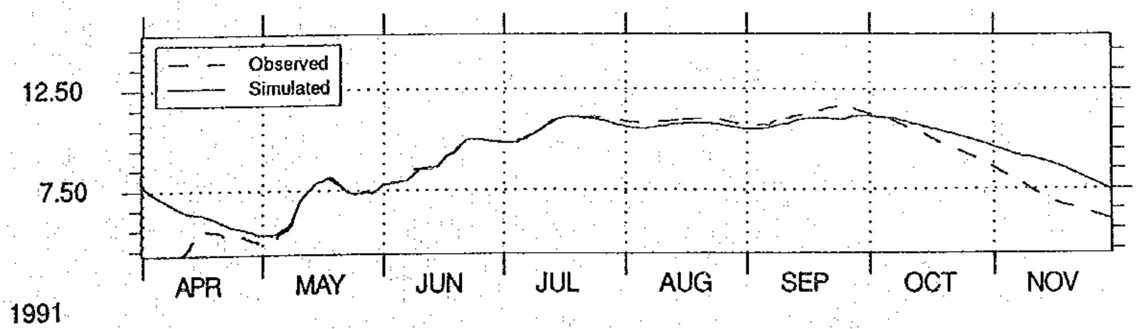


Figure 5.10 **Baral RB (wl)**

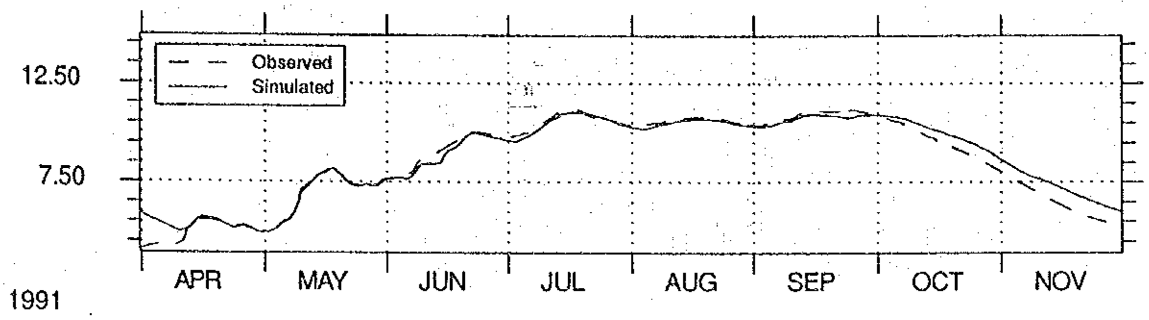


Figure 5.11 Dohakladanga (wl)

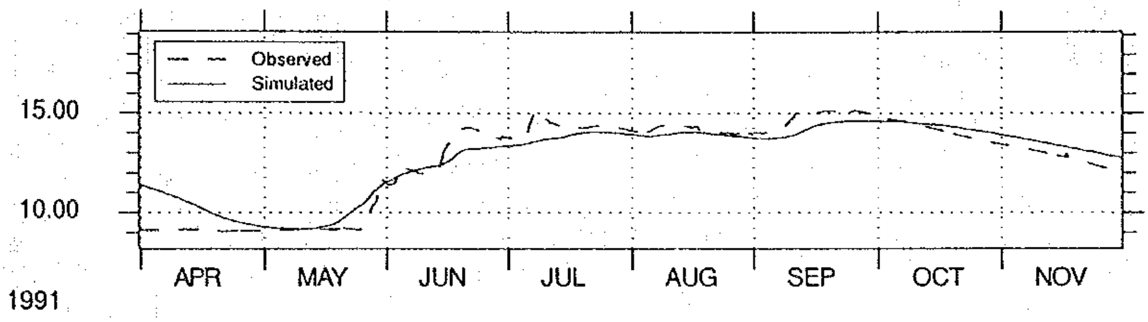


Figure 5.12 Nowhata (wl)

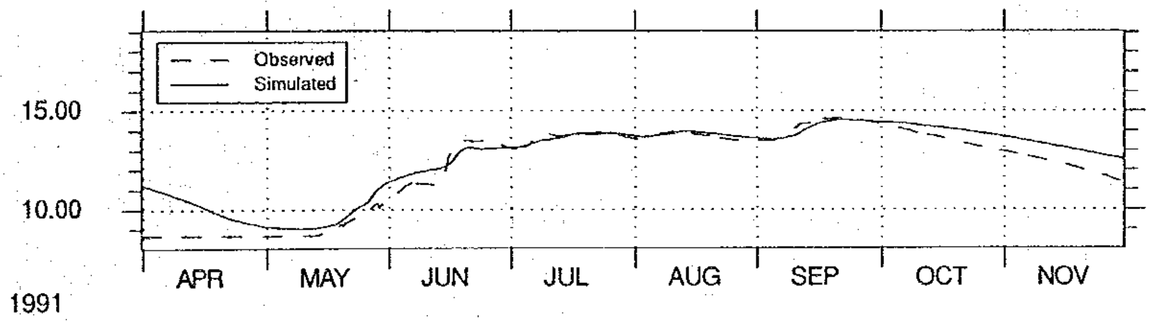


Figure 5.13 Bagmara (wl)

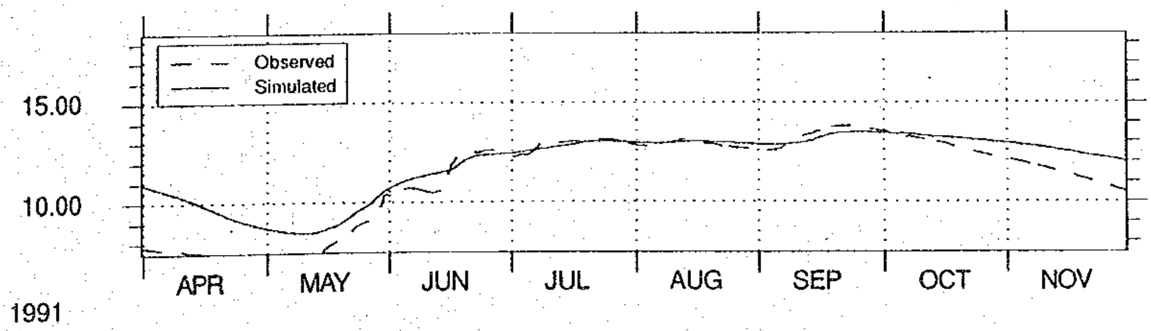


Figure 5.14 Naldanga RB (wl)

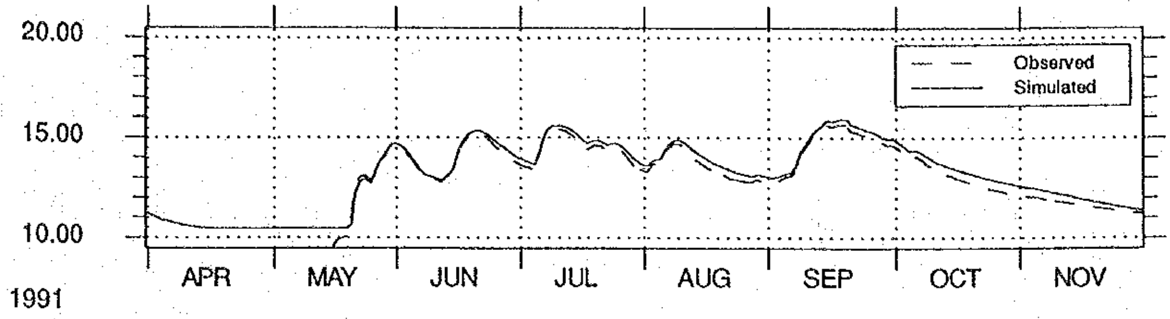


Figure 5.15 Naogaon (wl)

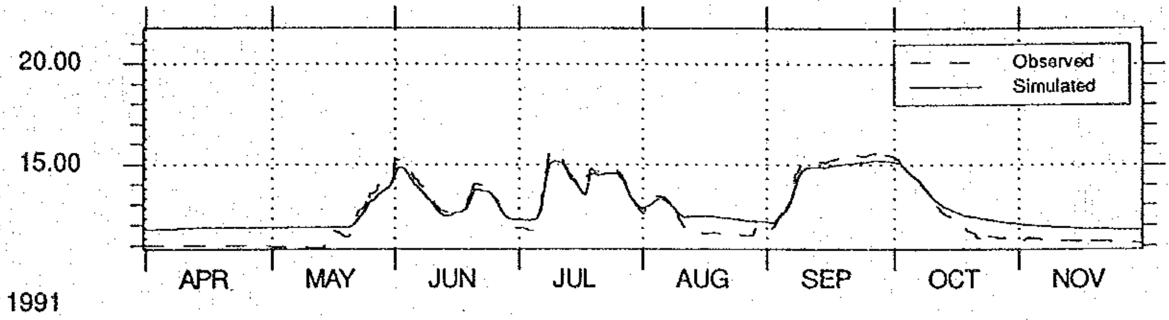


Figure 5.16 Talora (wl)

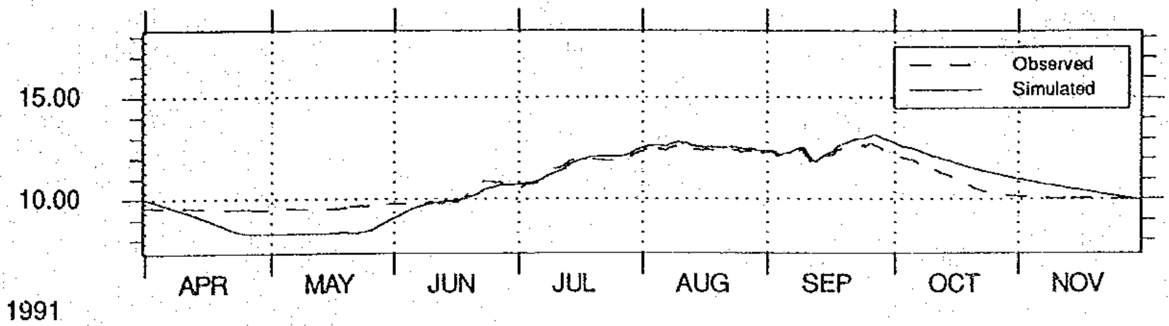


Figure 5.17 Malonchi (wl)

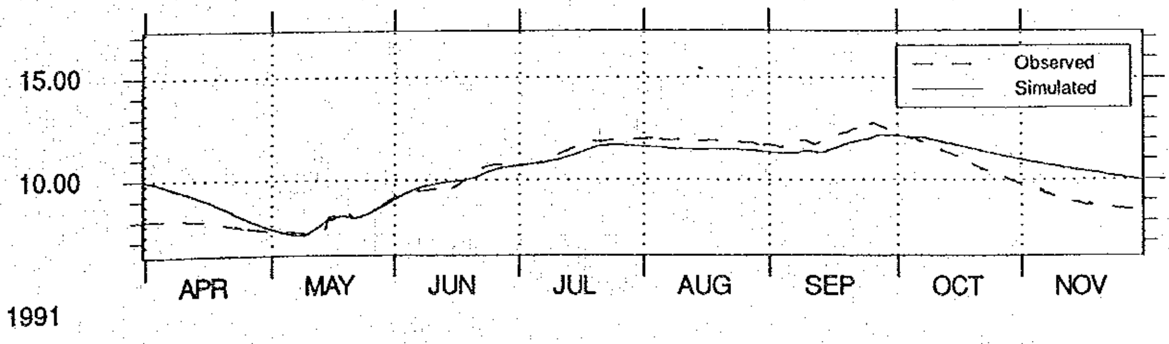


Figure 5.18 Halsa (wl)

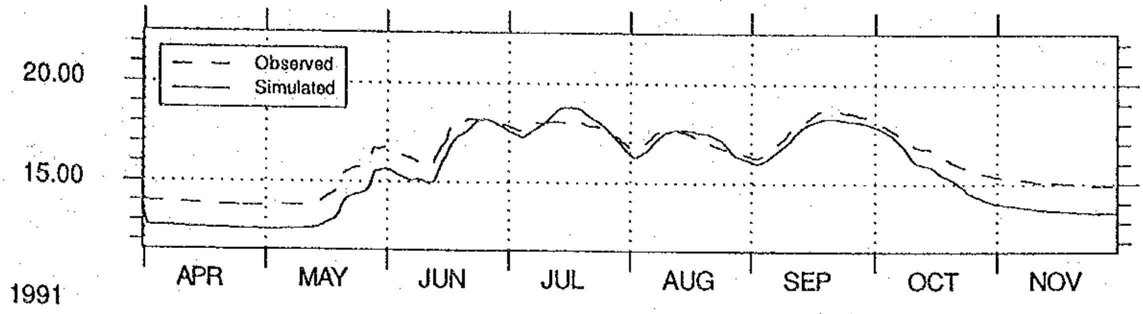


Figure 5.19 Mohimaganj (wl)

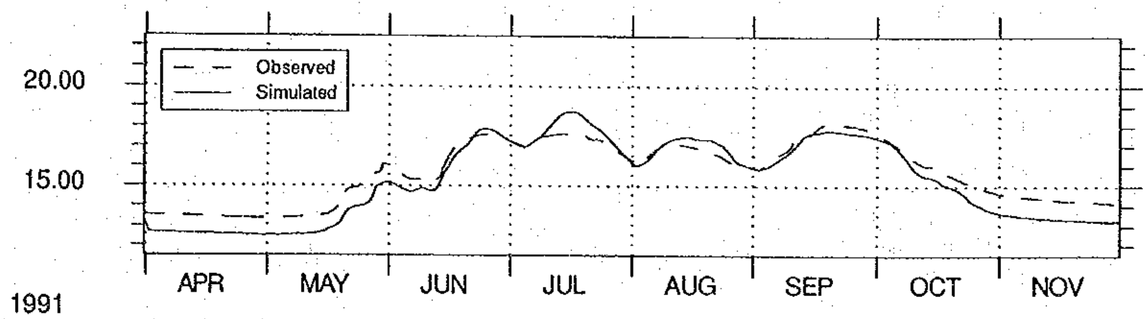


Figure 5.20 Simulbari (wl)

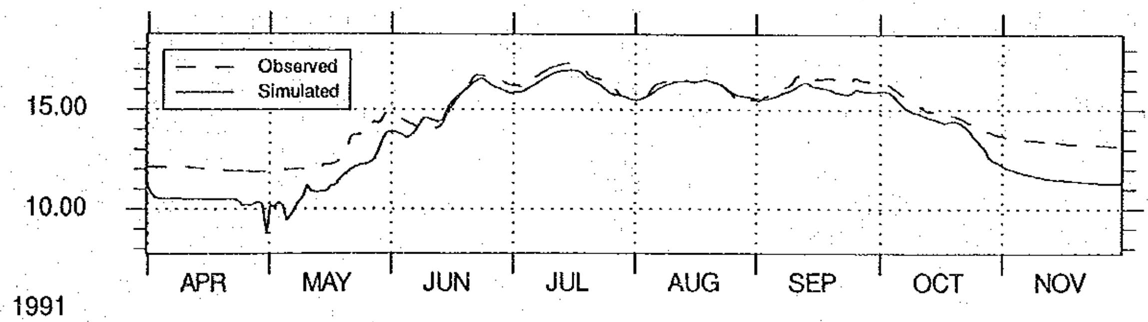


Figure 5.21 Sariakandi (wl)

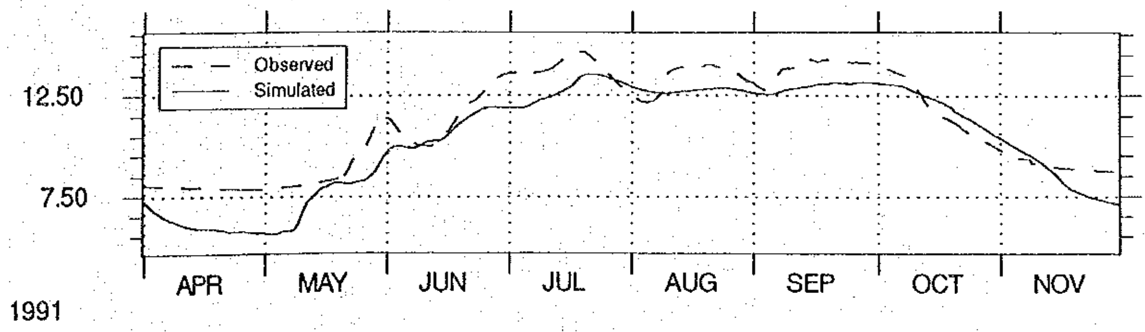


Figure 5.22 Khanpur (wl)

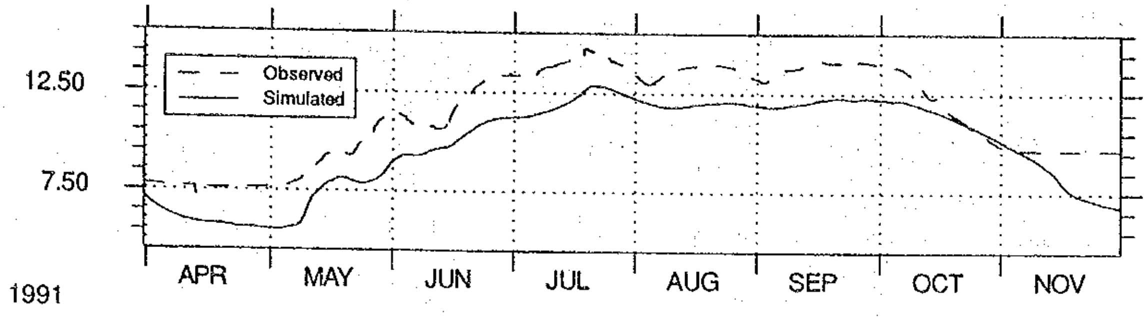


Figure 5.23 Raiganj (wl)

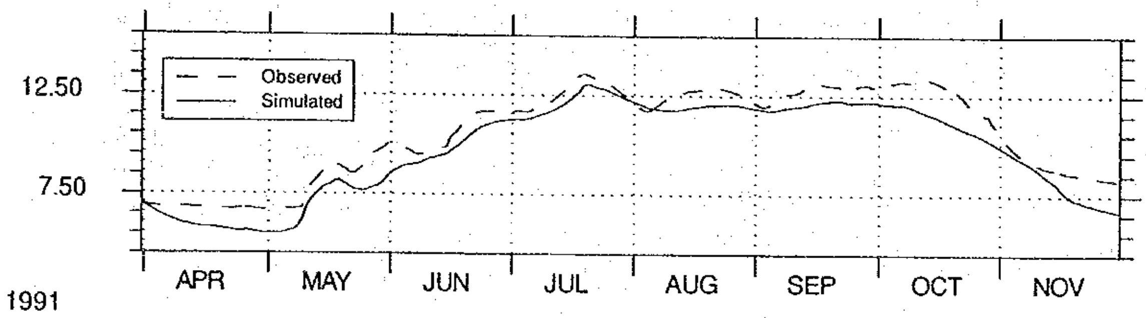


Figure 5.24 Nalkasengati (wl)

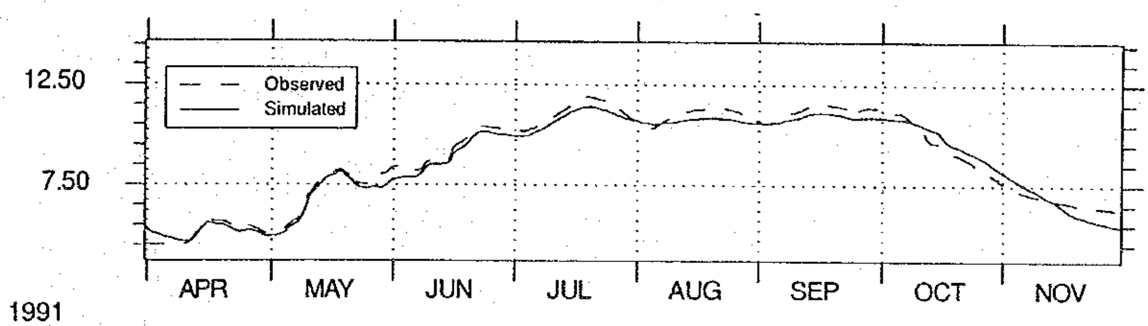


Figure 5.25 Ullapara (wl)

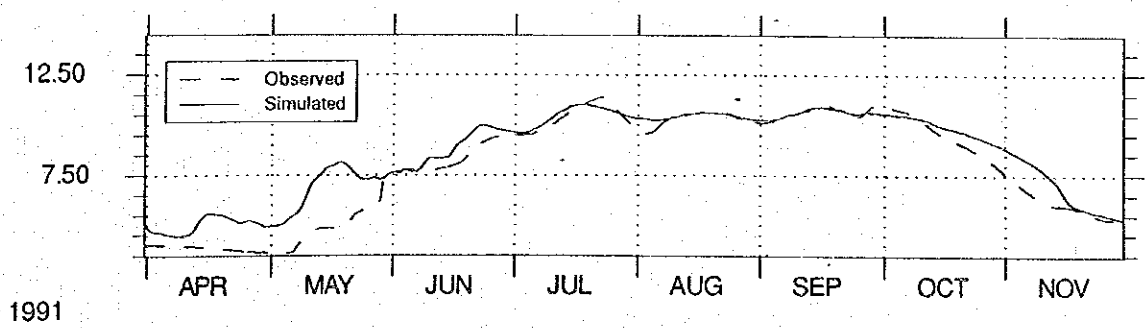


Figure 5.26 Nalgolar RB (wl)

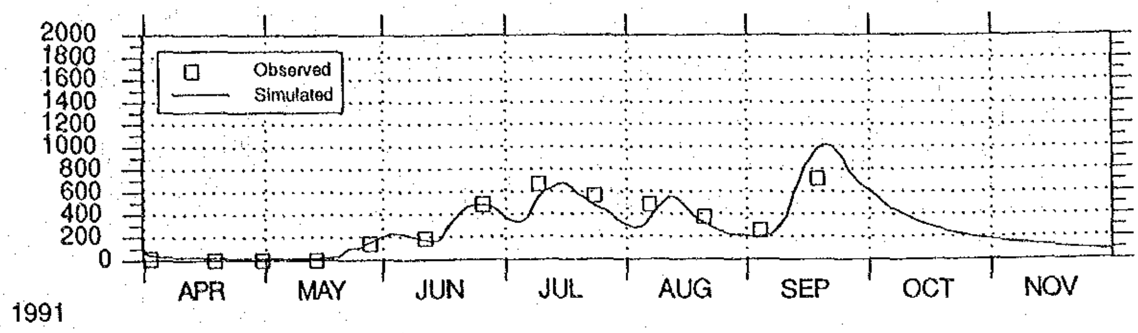


Figure 5.27 Atral RB (q)

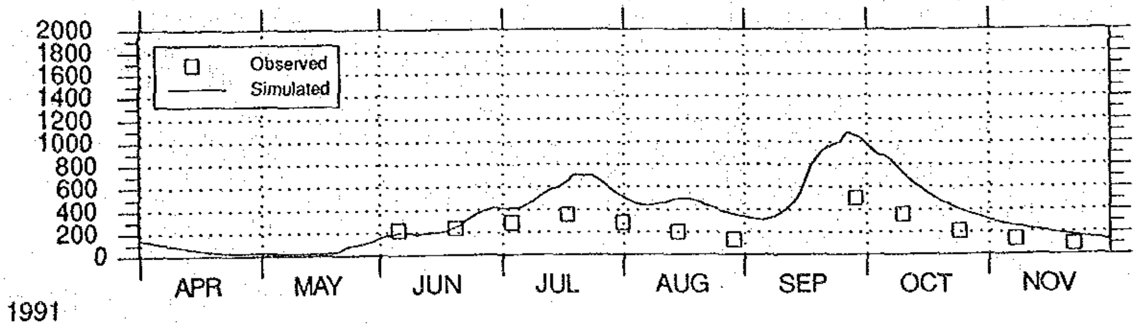


Figure 5.28 Singra (q)

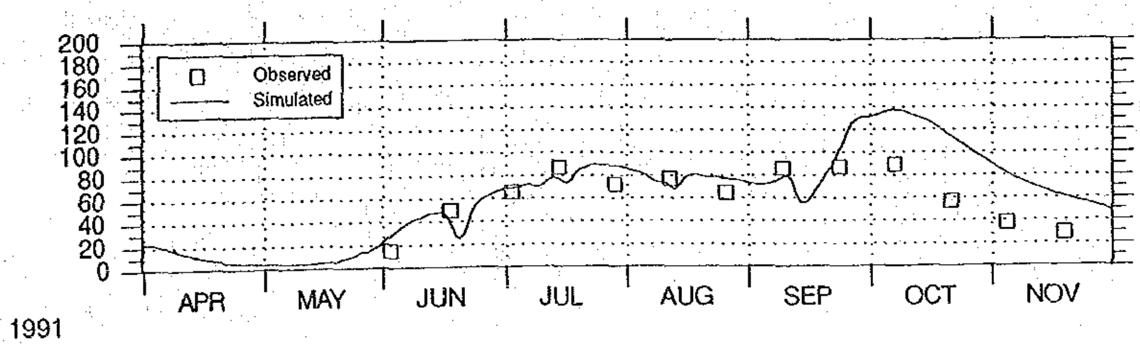


Figure 5.29 Baral RB (q)

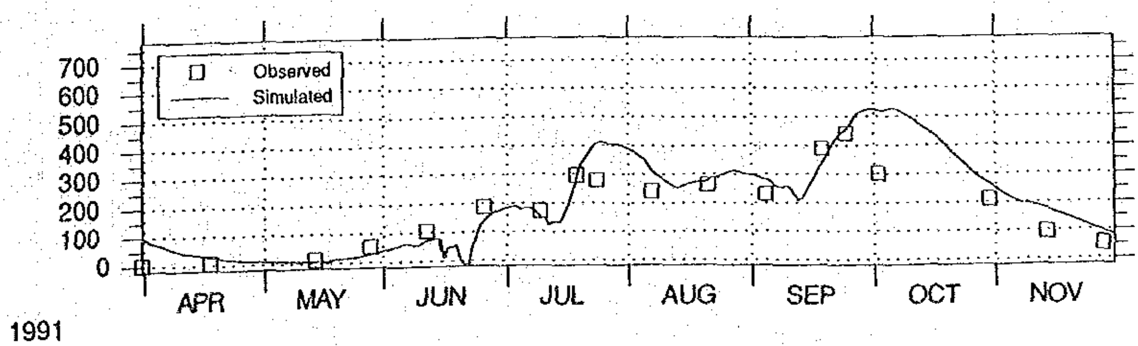


Figure 5.30 Nowhata (q)

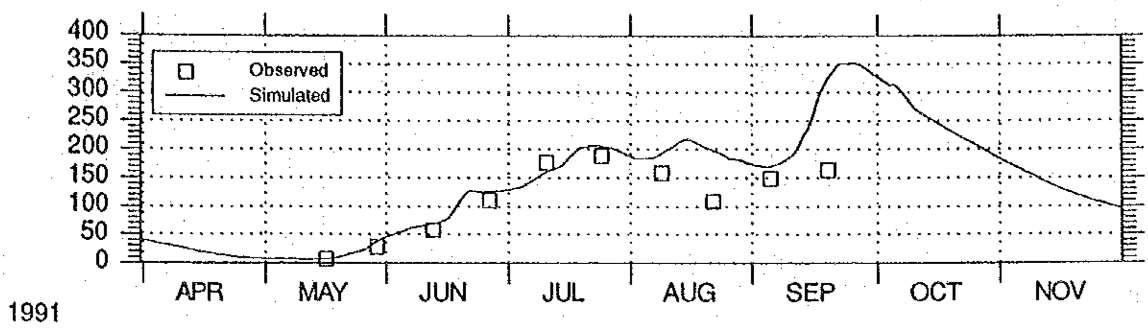


Figure 5.31 Naldanga RB (q)

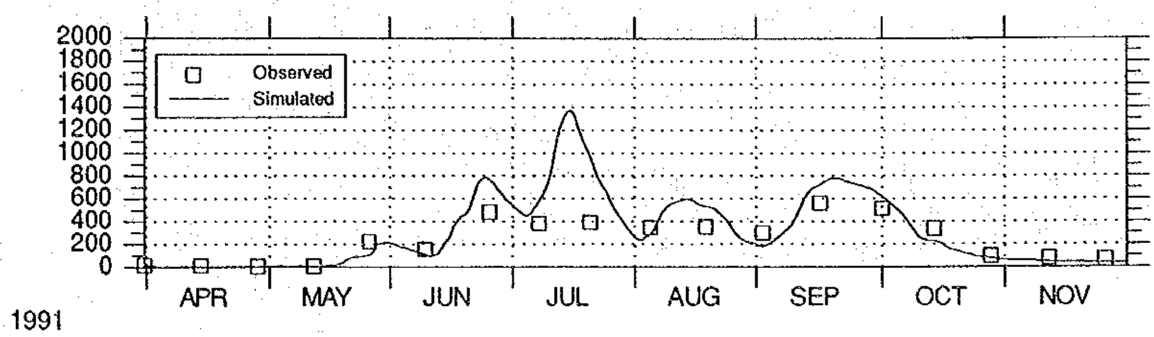


Figure 5.32 Simulbari (q)

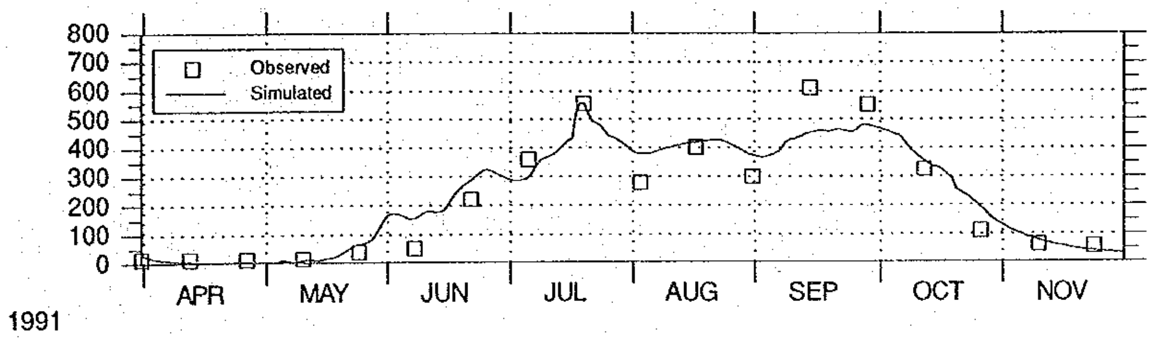


Figure 5.33 Khanpur (q)

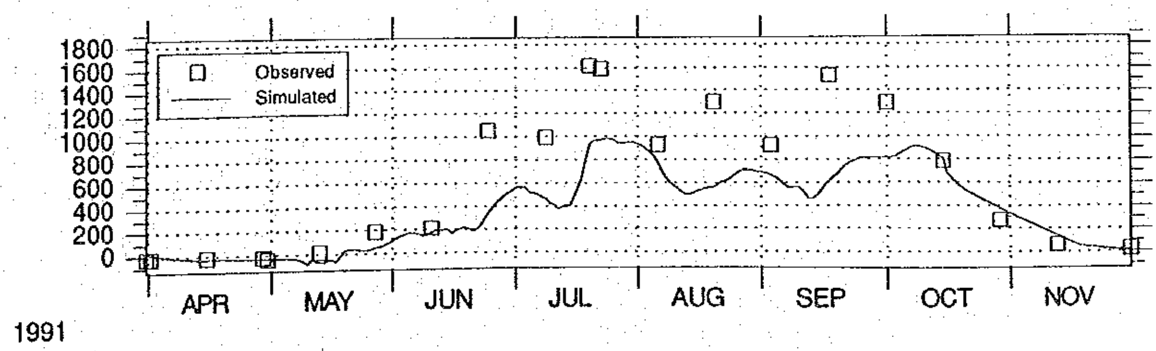


Figure 5.34 Ullapara (q)

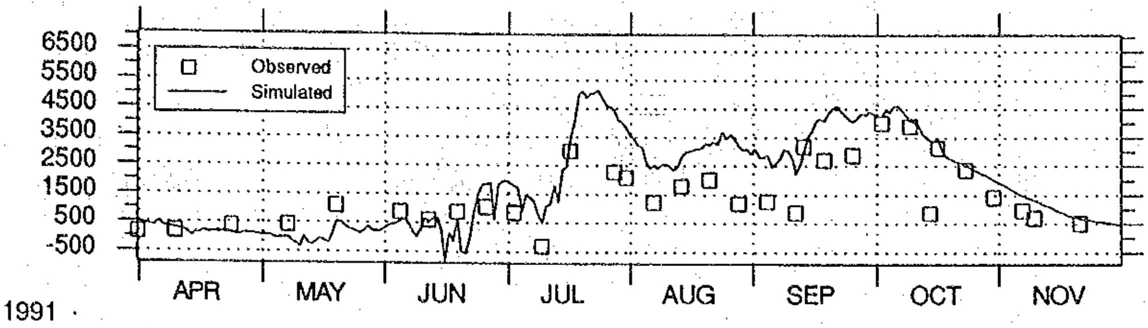


Figure 5.35 Baghabari (q)

CHAPTER 6

APPLICATION OF NUMERICAL MODEL IN DEFINING FLOOD/WATER PHASES AND CROPPING PATTERNS

6.1 Introduction

The output from MIKE11 is specifically orientated to provide water level and discharge time series at nodes within the modelled river system and these are used extensively to assist in the engineering design of flood control measures. However, when considering flood control measures it is also vitally important to be able to assess the impacts away from the main river courses on the floodplains.

A suite of post-processing programs were developed to provide additional data and information relating to the floodplains. In particular these were to assess the impact flood control measures would have on:

- the flooding regime of the floodplains (timing, depth and duration)
- the change this may make to future cropping patterns
- the change this would introduce on potential fisheries areas

In addition to its usefulness as a tool to provide additional primary and secondary data for use by other members of the study team, the analysis also served as additional verification of the model's ability to predict flooding regimes in areas away from the river system, that is, on the active floodplains.

Although these aspects are discussed in connection with the sub-regional model, these analysis techniques have also been used extensively within the Gaibandha Project area and also in the non-modelled areas, where the post-processing analysis is linked with the engineering drainage analyses.

6.2 General approach

6.2.1 Methodology

The procedure followed in obtaining water/flood phase, optimum cropping patterns, adjusted cropping patterns and potential fisheries areas is shown in the flow diagram given in Figure 6.1. The procedures is as follows:

Definition of areas : Each project area was divided into a number of sub-areas, in general 4 or more. The flood depth in each sub-area was represented by a single water level node from the hydraulic model analyses.

Water level output : The standard MIKE11 water level results were output to text files in five year blocks. The output was on a daily basis throughout the full hydrological year. This was done for each required node.

Water level analysis : The daily water level values were averaged on a 10 day, decade, basis. Hydrological analysis was carried out on the decade values to give minimum, mean and maximum water levels for each decade in the year. In addition, return period decade water levels were calculated for 2, 5, 10, 20, 50 and 100 year return periods.

Stage/area analysis : In order to be able to define flooded areas to different depths it is necessary to define the stage/area relationships of the appropriate project areas. This was undertaken using the SWMC digitising facilities which utilises the MPO square kilometer grid of spot heights.

Water phase analysis : The time dependent water phases of each sub-area are calculated based on the water level analysis and the stage/area relationships.

Flood phase analysis : Based on the water phase analysis, the flood phase was calculated corresponding to the MPO definition of flood phase.

Optimum cropping : Given a set of agronomic rules based on the planting dates, harvesting dates and tolerance to water depths, the optimum cropping patterns and areas were calculated based on the water phase analysis. The optimum cropping patterns were calculated for 100% and 0% irrigable land.

Adjusted cropping : Cropping patterns were adjusted for the percentage irrigation availability (which varies depending on whether present or future conditions were being considered) and the net cultivable area.

Fisheries areas : Based on the water phase analysis, the potential fisheries areas were calculated based on both timing and depth of the more permanent water bodies.

Following this approach, each of the above information can be calculated for different stages in time. In general, the approach was firstly to carry out the analysis for 'present' conditions. This was then verified against other sources of data such as MPO flood phases or BBS statistics on present cropping patterns/intensities and fisheries data. Following this, the process is repeated for a 'future without' situation in which various parameters may change due to changes in the flooding regime, increased irrigation potential or by other such factors. Finally, a third analysis is undertaken for the 'future with' project condition to enable the benefits or disbenefits of the proposed projects to be assessed.

The methodology given above is not restricted entirely to areas for which a hydraulic model was developed. The starting point for most of the analyses is the water phase data and this can be derived from standard drainage calculations and not only from model time series data. Within the study this analysis was undertaken extensively in both modelled and non-modelled areas of the region.

6.2.2 Water level analysis

Standard MIKE11 output produces time series water levels and discharges at any specified node within the modelled area. From this data, hydrological analysis can be undertaken to give a wide range of variables which may be of use in the design of engineering works, general level of flooding or for agricultural and fisheries assessment.

A suite of analysis programs developed by the hydrology team have been used. For the post-processing described in this Chapter an analysis of 10 daily (decade) water levels was used.

Typical output for the water level analysis is shown in Table 6.1. From the results of a model simulation the minimum, mean and maximum water levels for each decade in the year were calculated. In addition, return period water levels were calculated for 2, 5, 10, 20, 50 and 100 year return periods. A Blom formula was used for the lower return periods, up to 1 in 20 year for a 25 year series and up to 1 in 10 year for a 10 year series, and a Gumbel Extreme Value analysis for the higher return periods.

For the purposes of this study the length of the model simulations were generally 10 or 25 year simulations which meant that the reliability of the return period estimates for a 1 in 5 year event were reasonable. Estimates for high return periods should be viewed with caution because they result from extrapolation beyond the period of model simulation.

6.2.3 Water phase analysis

'Water phase' is used to define areas flooded to different depths throughout the flood season. This differs from the more generally used 'flood phase' definition in that it has a finer resolution of the flood depth categories and is time dependent. Water phases in the following depth categories were calculated:

0.0 - 0.3 m
0.3 - 0.7 m
0.7 - 1.0 m
1.0 - 1.5 m
1.5 - 3.0 m
> 3.0 m

These depth categories were selected on agronomic criteria; the tolerance of different crops to different flood depths at the various stages of their growth.

Although water phases could be calculated on a daily basis, if required, discussions within the study team suggested that a more appropriate time period for these post-processing applications was to analyse the depth of flooding on a 10 day or decade basis; this is particularly relevant to agricultural conditions whereby crop tolerance is generally measured in days rather than hours. It also gives a more generalised picture of the flooding regime by averaging short duration fluctuations.

Based on the water level analysis and the stage/area relationship, areas flooded to different depth categories were calculated for each decade through the hydrological year. Typical output from this analysis is given in Table 6.2 which gives the areas flooded to different depth categories for each decade. This information can also be supplied as a percentage of the total area, Table 6.3. The 1 in 5 year return period levels were used for this analysis.

6.2.4 Flood phase analyses

The widely adopted MPO flood phase figures are not quoted with respect to a time element whereas the model output and flood levels at each node are produced as a time series. The depth categories for flood phases are also defined differently from those for the water phase analysis; the water phase categories having a higher resolution.

Water phases fall in to the following depth categories in relation to the flood phase categories:

0.0 - 0.3 m	F0 land
0.3 - 0.7 m	F1 land
0.7 - 1.0 m	F1&2 land
1.0 - 1.5 m	F2&3 land
1.5 - 3.0 m	F2&3 land
> 3.0 m	F3&4 land

These can be easily transformed into the more widely used flood phase categories by redistributing the flood depth categories to correspond to:

0.0 - 0.3 m	F0 land
0.3 - 0.9 m	F1 land
0.9 - 1.8 m	F2 land
1.8 - 3.6 m	F3 land
> 3.6 m	F4 land

However, this does not eliminate the time dependent nature of the water phase information.

A wide range of sensitivity tests were undertaken to try and establish the correlation between water phases and flood phases, based on the published MPO flood phase figures. These tested the sensitivity of the correlation between the two to:

- the representative return period decade water level
- the period of flood exceedance

In total, 12 alternative ways of assessing the flood phases were considered, for different combinations of return period level (mean water, 5, 10 and 20 year levels) and flood exceedance periods (May to November, July to September, and severest flood depth).

These sensitivity tests showed that the most suitable method of converting water phase to flood phase was to select the 1 in 5 year return period level and take the peak decade flood level. This ties in particularly well with field information in that farmers have indicated that, in general, they are prepared to risk crop damage one year in every five. Typical output for this analysis is given in Table 6.4 which gives the flood phase distribution in each sub-area and that for the area as a whole.

6.2.5 Optimum cropping patterns

The following agronomic principles were followed in calculating cropping patterns from the water phase data :

Irrigated areas

HYV Boro : 0-30 cm between February/1 and May/1, not above 70 cm until June/1.

HYV t aman	:	<u>either</u>: 0-30 cm between August/1 and September/3. Not above 70 cm until November/3. This will be late HYV t aman. <u>or</u> : 0-30 cm between July/2 and August/2, not more than 70 cm until November/3. This will be early HYV t aman.
L t aman	:	<u>either</u>: 0-30 cm between August/3 and October/1, not more than 70 cm until October/3 and 100 cm until November/3. This will be late l t aman. <u>or</u> : 0-30 cm between July/2 and August/3, not more than 70 cm until September/3 and 70-100 cm until November/3. This will be early l t aman.
TDW aman	:	0-30 cm between June/1 and July/2, not more than 300 cm until November/3.
Rabi crops	:	0-30 cm in November/2 and not cropped in September to November/1.

Non-irrigated areas

B aus	:	0-30 cm between March/2 and May/3, not more than 70 cm until June/3 and not more than 100 cm until August/1.
Jute	:	0-30 cm between March/2 and May/1, not more than 70 cm until May/2 and not more than 150 cm until August/2.
HYV t aman	:	0-30 cm between August/1 and September/3. Not above 70 cm until November/3. This corresponds to "HYV t aman (late)" in the irrigation scenario.
L t aman	:	0-30 cm between August/3 and October/1, not more than 70 cm until October/3 and 100 cm until November/3. This corresponds to "l t aman (late)" in the irrigation scenario.
B aman	:	0-30 cm between March/2 and April/3, not more than 70 cm between May/1 and June/2 and not more than 300 cm until November/2.
Rabi crops	:	0-30 cm in November/2 and not cropped in September/November/1.
(Note	:	June/3 is the 3rd decade in June, etc.)

These agronomic principles were used to assess optimum cropping patterns under the assumption, firstly, that the area has 100% irrigation and, secondly, that the area is non-irrigated. These can then be refined to take account of the actual level of irrigation capability for different periods such as present conditions or some future conditions.

From the optimum cropping patterns a 'selected' cropping pattern was derived by including a priority basis for different crops; that is, taking account of farmers preferences and the economic value of different crops. A typical example is shown in Table 6.5.

6.2.6 Adjusted cropping analysis

The selected cropping patterns calculations for irrigated and non-irrigated scenarios were blended according to the required, or specified, level of irrigation to obtain a final adjusted, potential, cropping pattern (Table 6.6). Further adjustment was made to allow for homesteads, roads, water bodies and other non-agricultural uses of land; the gross cultivable area (GCA) being converted into a net cultivable area (NCA). In general, the areas allocated to B aus and the T aman crops was reduced to take account of the difference between GCA and NCA.

A more detailed agronomical description of the procedure to calculate cropping patterns is given in the Agriculture Annex.

6.2.7 Fisheries analysis

Flood control measures can have both disbenefits and benefits in terms of capture fisheries. From the water phase analysis it was possible to estimate the potential fisheries areas. Within each project area or sub-project area, the capture fisheries area on the floodplains was defined from the following fisheries principles:

- the area requires water depths to be greater than or equal to F1 land (ie deeper than 30cm)
- the water body must remain for a minimum of 3 months of the year without drying up

Based on these two principles the areas potentially suitable for fisheries could be defined. Typical output is given in Table 6.7.

6.3 Verification of analyses

6.3.1 General

As outlined in Section 6.2.1 the usefulness of this post-processing analysis first requires that the method is verified against other sources of information.

For the verification exercise, published data on the MPO flood phases and BBS statistics were used. This data is generally published on a thana or upazilla basis. This was converted to a project by distributing the statistics on a prorate basis according to the percentage area which falls within the individual project areas.

6.3.1 Comparison of flood phases

A number of assumptions were made regarding the calculation of flood phases. Firstly, it was assumed that non-cultivatable area was deducted from the 0-0.3 m depth category, F0 land, as much

of this land will be for homesteads, etc, and will generally lie above the average flooding level. Secondly, it was assumed that the flood level is 'horizontal' within each sub-area. Whilst this will generally be true in low lying deeply flooded areas it may not be correct in some of the more northerly areas of the sub-regional area. Furthermore, the development of stage/area curves for these areas is on a coarse scale, one spot level per square kilometre, and this cannot possibly define the micro-topography of the region. This micro-topography will play a crucial role in the definition of flood phases as even slightly depressed localised areas which accumulated rainfall to a depth greater than 0.3m would transform these from on F0 to F1 classification. Finally, and perhaps most crucially, the MPO flood phase figures were taken as being representative of the present flood phasing; other flood phase data was considered but it was felt that the MPO data was infact closer to the true situation observed during field visits.

In order to confirm that the procedure developed was applicable over a wide range of areas flood phases were calculated for present conditions and compared with the MPO flood phase data for these areas. The results of this comparison are presented in Figure 6.2.

For Chalan Beel Polders A, B and C, Bogra Polder 3 and Naogaon polder the agreement between the model predicted flood phases and those presented by MPO is extremely good. For Chalan Beel Polder D the model under estimates the percentage of F0 land and over estimates the percentage of F3+F4 land. For Bogra Polder 2 the model over estimates the percentage of F2 land and under estimates the percentage of F3+F4 land. In SIRDP the model over estimates the percentage of F0 and F3+F4 land and under estimates the percentage of F1 land.

The main purpose of using the model to estimate flood phases is as a basis for the automated calculation of cropping patterns. From an agricultural point of view the critical factor is the split between F0+F1 land to that which is flooded deeper. It can be seen from Figure 6.2 that, in general, the model adequately represents this split in all project areas.

It can be concluded that the model generated flooding phases agree reasonably well with the MPO figures and that they form an acceptable basis for the automatic calculation of cropping patterns and the assessment of with and without project conditions.

6.3.2 Comparison of cropping patterns

Agricultural benefits mainly come from increasing the area of transplanted rice at the expense of monsoon fallow or broadcast rice. Boro in the North West region can only be substantially increased by additional irrigation facilities and in general the restriction to boro due to flooding is minimal in the Lower Atrai area. Thus, from an agricultural viewpoint, the issue is how can the areas of transplanted aman, HYV or local, be increased and how accurately can the developed procedures predict this increase.

In order to confirm that the procedure developed above was applicable to a large range of different areas calculated cropping patterns were compared with the BBS cropping statistics for 1989. The project areas in the Lower Atrai basin were selected for this comparison. In the various project areas the model predicted area of HYV and l t aman was compared with the BBS statistics. The results of this analysis are presented in Table 6.8.

TABLE 6.8
Comparison of model predicted areas of HYV and t aman BBS statistics for 1989

	Calculated	BBS in 1989	Total area
Naogaon	20,061	19,813	42,982
SIRDP	20,550	17,236	72,955
Chalan Beel A	11,618	11,583	30,214
Chalan Beel B	12,632	9,128	35,562
Chalan Beel D	16,502	16,627	57,460
Bogra Polder 2	26,940	26,692	56,395
Total	108,303 (36.6%)	101,079 (34.2%)	295,568 (100 %)

Table 6.8 illustrates a reasonable agreement between the model predicted areas of HYV and l t aman and those presented in the BBS statistics. It is also to be noted that the 1989 data reported the t aman of 1988 which, because it was a flood year, was lower than normal, thereby probably lessening the difference even further. It can be concluded that the model generated cropping patterns agree reasonably well with the BBS figures and that they form an acceptable basis of primary or secondary data on which to assess different development options.

6.4 Possible refinements to procedure for calculating cropping patterns

The procedures and methodology outlined in this Chapter potentially provide a powerful analytical tool for providing information on the benefits and disbenefits of different project proposals. There are however many areas in which the procedures could be refined to make them more widely applicable and more sensitive to a greater number of variables.

The procedure described above for calculating the cropping patterns uses the 1 in 5 year return period water level for each decade of the year. These water levels are calculated from the daily water levels for the duration of the model simulation - this could be 5, 10 or 25 years. Clearly there is a great deal more information available from the model simulation than is actually used in the automated cropping pattern procedure. Some of the discrepancies which exist may be eliminated if more of this information were to be used.

An alternative procedure should be investigated which uses the model results for each year of simulation. This would produce cropping patterns for each year; if necessary these could be averaged to obtain a single, average cropping pattern. Using this procedure the predicted cropping patterns would reflect the year to year variations in the depth and duration of flooding.

The present procedure for calculating cropping patterns requires the preferences between different crops to be clearly stated. In the current procedure this can only be based on flooding depth and duration considerations. The development of procedures which allow different factors to be used to

determine preferences should be investigated. Factors which could be taken into account could include,

- variations in crop timing in different areas
- environmental factors such as rainfall
- costs
- marketing considerations
- social factors such as labour availability

Even when all these factors are taken into consideration it may not be possible to pre-define cropping preferences. Linear programming could be used to take account of all the above considerations and to and produce an optimisation to the cropping pattern analysis.

TABLE 6.1
Example output - Water level analysis (decad basis)

ANALYSIS OF 10-DAY MEAN WATER LEVELS
(Model output for 24 years - run W)

POLC_ART (PLC) Chainage 3.000

		Min.	Mean	Max.	Return Period (years) 2	5	10	20	50	100
Apr	1	10.13	10.44	10.98	10.43	10.77	10.83	10.96	11.06	11.16
	2	10.13	10.37	10.96	10.25	10.61	10.87	10.93	11.09	11.22
	3	10.13	10.38	10.95	10.20	10.71	10.93	10.94	11.16	11.31
May	1	10.13	10.47	11.04	10.38	10.90	10.95	11.03	11.25	11.39
	2	10.13	10.69	11.42	10.88	11.02	11.07	11.28	11.33	11.41
	3	10.13	10.97	11.92	11.00	11.31	11.60	11.88	11.95	12.12
Jun	1	10.13	11.16	12.15	11.11	11.47	11.78	11.93	12.12	12.30
	2	10.35	11.53	12.70	11.37	11.72	12.59	12.64	12.94	13.21
	3	10.82	11.95	12.79	12.04	12.58	12.66	12.76	12.97	13.11
Jul	1	11.11	12.32	13.04	12.37	12.68	12.73	12.93	13.04	13.15
	2	11.41	12.61	13.12	12.69	12.98	13.03	13.08	13.18	13.24
	3	12.14	12.87	13.48	12.92	13.19	13.36	13.42	13.53	13.63
Aug	1	12.31	12.93	13.58	12.90	13.15	13.52	13.57	13.66	13.79
	2	12.12	12.76	13.60	12.60	13.22	13.38	13.54	13.76	13.95
	3	12.14	12.73	13.59	12.74	13.09	13.32	13.49	13.60	13.74
Sep	1	11.87	12.70	13.47	12.72	13.12	13.33	13.39	13.57	13.71
	2	12.01	12.73	13.40	12.71	13.04	13.20	13.31	13.39	13.49
	3	12.17	12.76	13.40	12.72	13.16	13.28	13.34	13.52	13.65
Oct	1	12.02	12.67	13.28	12.67	13.01	13.13	13.25	13.35	13.46
	2	11.63	12.49	13.45	12.45	12.83	13.21	13.37	13.48	13.66
	3	11.37	12.19	12.87	12.14	12.59	12.77	12.86	13.00	13.12
Nov	1	11.25	11.83	12.46	11.79	12.19	12.32	12.41	12.54	12.65
	2	11.16	11.53	12.15	11.45	11.85	11.95	12.05	12.19	12.29
	3	11.05	11.29	11.82	11.20	11.51	11.59	11.69	11.80	11.89
Dec	1	10.84	11.14	11.47	11.13	11.24	11.31	11.38	11.43	11.48
	2	10.62	11.04	11.22	11.08	11.14	11.17	11.19	11.21	11.24
	3	10.40	10.98	11.11	11.02	11.09	11.10	11.11	11.14	11.16
Jan	1	10.33	10.94	11.11	10.99	11.05	11.08	11.09	11.12	11.13
	2	10.38	10.92	11.09	10.97	11.03	11.07	11.09	11.11	11.14
	3	10.34	10.89	11.08	10.96	11.02	11.05	11.07	11.09	11.11
Feb	1	10.21	10.85	11.07	10.92	10.99	11.02	11.04	11.07	11.10
	2	10.13	10.80	11.05	10.88	10.96	10.97	11.02	11.05	11.07
	3	10.13	10.75	11.05	10.84	10.93	10.96	11.02	11.04	11.07
Mar	1	10.13	10.70	11.05	10.80	10.90	10.96	11.03	11.05	11.09
	2	10.13	10.62	11.01	10.77	10.87	10.91	10.96	11.00	11.03
	3	10.13	10.53	10.94	10.63	10.84	10.87	10.91	10.97	11.02

Note: Estimates for return periods of more than 20 years should be viewed with particular caution because they result from extrapolation beyond the period of model simulation.

TABLE 6.2
Example output - Water phase analysis by area

Water phase analysis

Analysis for Future Without - Polder C - 25yr (wout)
Water levels based on 1:5 year levels
Area flooded in depth categories - Total Area

Month	10 day	Depth categories (m) 0.0-0.3	0.3-0.7	0.7-1.0	1.0-1.5	1.5-3.0	>3.0
4	1	42380.	0.	0.	0.	0.	0.
4	2	42380.	0.	0.	0.	0.	0.
4	3	42380.	0.	0.	0.	0.	0.
5	1	42380.	0.	0.	0.	0.	0.
5	2	42380.	0.	0.	0.	0.	0.
5	3	41454.	926.	0.	0.	0.	0.
6	1	38056.	3560.	764.	0.	0.	0.
6	2	36017.	4377.	1553.	433.	0.	0.
6	3	28931.	4725.	2974.	4618.	1131.	0.
7	1	24693.	4034.	3211.	4761.	5681.	0.
7	2	21549.	3683.	3218.	5419.	8512.	0.
7	3	19341.	3847.	2477.	5327.	11225.	162.
8	1	18347.	3370.	2447.	4470.	12892.	854.
8	2	18415.	3474.	2484.	4792.	12651.	563.
8	3	18623.	3449.	2342.	4419.	12731.	815.
9	1	18580.	3457.	2415.	4623.	12641.	664.
9	2	19131.	3568.	2242.	4622.	12223.	594.
9	3	18817.	3699.	2193.	4668.	12364.	639.
10	1	19333.	3543.	2244.	4604.	12082.	574.
10	2	20255.	3263.	2379.	4381.	11626.	477.
10	3	22069.	3111.	2673.	4710.	9661.	157.
11	1	24969.	3392.	2773.	5044.	6202.	0.
11	2	27882.	3534.	3394.	3635.	3934.	0.
11	3	31193.	4421.	2203.	3570.	992.	0.
12	1	35250.	3116.	2378.	1507.	129.	0.
12	2	37948.	3217.	869.	346.	0.	0.
12	3	40003.	1984.	393.	0.	0.	0.
1	1	41519.	861.	0.	0.	0.	0.
1	2	42009.	371.	0.	0.	0.	0.
1	3	42256.	124.	0.	0.	0.	0.
2	1	42380.	0.	0.	0.	0.	0.
2	2	42380.	0.	0.	0.	0.	0.
2	3	42380.	0.	0.	0.	0.	0.
3	1	42380.	0.	0.	0.	0.	0.
3	2	42380.	0.	0.	0.	0.	0.
3	3	42380.	0.	0.	0.	0.	0.

Note : all areas in hectares

TABLE 6.3
Example output - Water phase analysis by percentage area

Water phase analysis

Analysis for Future Without - Polder C - 25yr (wout)
Water levels based on 1:5 year levels
Area flooded in depth categories - Total Area

Depth categories (m)

Month	10 day	0.0-0.3	0.3-0.7	0.7-1.0	1.0-1.5	1.5-3.0	>3.0
4	1	100	0	0	0	0	0
4	2	100	0	0	0	0	0
4	3	100	0	0	0	0	0
5	1	100	0	0	0	0	0
5	2	100	0	0	0	0	0
5	3	98	2	0	0	0	0
6	1	90	8	2	0	0	0
6	2	85	10	4	1	0	0
6	3	68	11	7	11	3	0
7	1	58	10	8	11	13	0
7	2	51	9	8	13	20	0
7	3	46	9	6	13	26	0
8	1	43	8	6	11	30	2
8	2	43	8	6	11	30	1
8	3	44	8	6	10	30	2
9	1	44	8	6	11	30	2
9	2	45	8	5	11	29	1
9	3	44	9	5	11	29	2
10	1	46	8	5	11	29	1
10	2	48	8	6	10	27	1
10	3	52	7	6	11	23	0
11	1	59	8	7	12	15	0
11	2	66	8	8	9	9	0
11	3	74	10	5	8	2	0
12	1	83	7	6	4	0	0
12	2	90	8	2	1	0	0
12	3	94	5	1	0	0	0
1	1	98	2	0	0	0	0
1	2	99	1	0	0	0	0
1	3	100	0	0	0	0	0
2	1	100	0	0	0	0	0
2	2	100	0	0	0	0	0
2	3	100	0	0	0	0	0
3	1	100	0	0	0	0	0
3	2	100	0	0	0	0	0
3	3	100	0	0	0	0	0

Note : all areas in hectares

TABLE 6.4
Example output - flood phase analysis

Flood phase analysis

Analysis for Future Without - Polder C - 25yr (wout)

Water levels based on 1:5 year levels

Sub-unit	F0	F1	F2	F3&4
C4	56.	18.	14.	11.
C3	52.	16.	20.	12.
C2	5.	11.	29.	55.
C1	2.	7.	27.	64.

Total F0 land	33.
Total F1 land	14.
Total F2 land	22.
Total F3 & F4 land	31.

All figures in percent (%)

TABLE 6.5
Example output - Optimum cropping patterns

Optimum cropping patterns for the project area

Analysis for Future Without - Polder C - 25yr (wout)

Water levels based on 1:5 year levels

Irrigated cropping

Crop	Potential	Percent	Selection	Percent
Boro	41616.	98.2	41616.	98.2
HYV t aman (late)	18220.	43.0	0.	0.0
HYV t aman (early)	18220.	43.0	18220.	43.0
Local t aman (late)	18393.	43.4	173.	0.4
Local t aman (early)	18220.	43.0	0.	0.0
TDW aman (<3m)	21549.	50.8	3156.	7.4
TDW aman (>3m)	0.	0.0	0.	0.0
Rabi	27883.	65.8	6334.	14.9
Percent				164.0

Non-irrigated cropping

Crop	Potential	Percent	Selection	Percent
B aus	24096.	56.9	24096.	56.9
Jute	28573.	67.4	4477.	10.6
HYV t aman (late)	18220.	43.0	18220.	43.0
Local t aman (late)	18393.	43.4	173.	0.4
B aman (<3m)	40354.	95.2	11781.	27.8
B aman (>3m)	0.	0.0	0.	0.0
Rabi	27883.	65.8	4105.	9.7
Percent				148.3

TABLE 6.6
Example output - Adjusted cropping patterns

Adjusted cropping patterns for the project area

Analysis for Future Without - Polder C - 25yr (wout)

Water levels based on 1:5 year levels

Crop	Potential	Percent
Boro	30336.	71.4
HYV t aman (late)	3012.	7.1
HYV t aman (early)	13283.	31.3
Local t aman (late)	184.	0.4
Local t aman (early)	0.	0.0
TDW aman (<3m)	2286.	5.4
TDW aman (>3m)	0.	0.0
B aus	5107.	12.0
Jute	1598.	3.8
B aman (<3m)	4192.	9.9
B aman (>3m)	0.	0.0
Rabi	6065.	14.3
Total	66064.	155.5

GCA = 45970.
NCA = 42498.
IRR % = 67.2

TABLE 6.7
Example output - Potential fisheries areas

Fish areas for the project area

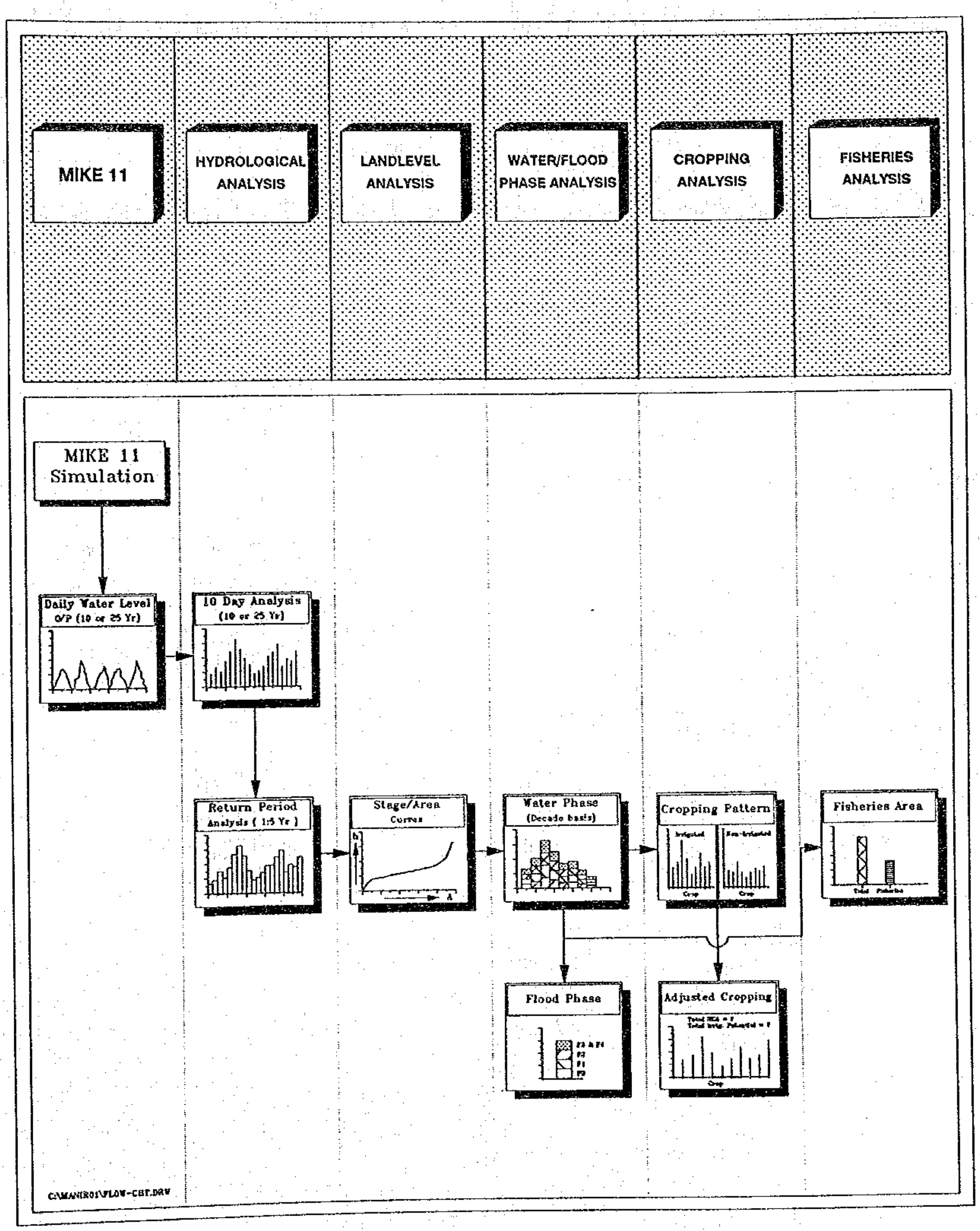
Analysis for Future Without - Polder C - 25yr (wout)

Water levels based on 1:5 year levels

Cell	Area	Percent
1	2896.	30.7
2	5654.	36.9
3	8616.	75.9
4	4985.	79.5
	22151.	52.3

Figure 6.1

Post Processing Analysis



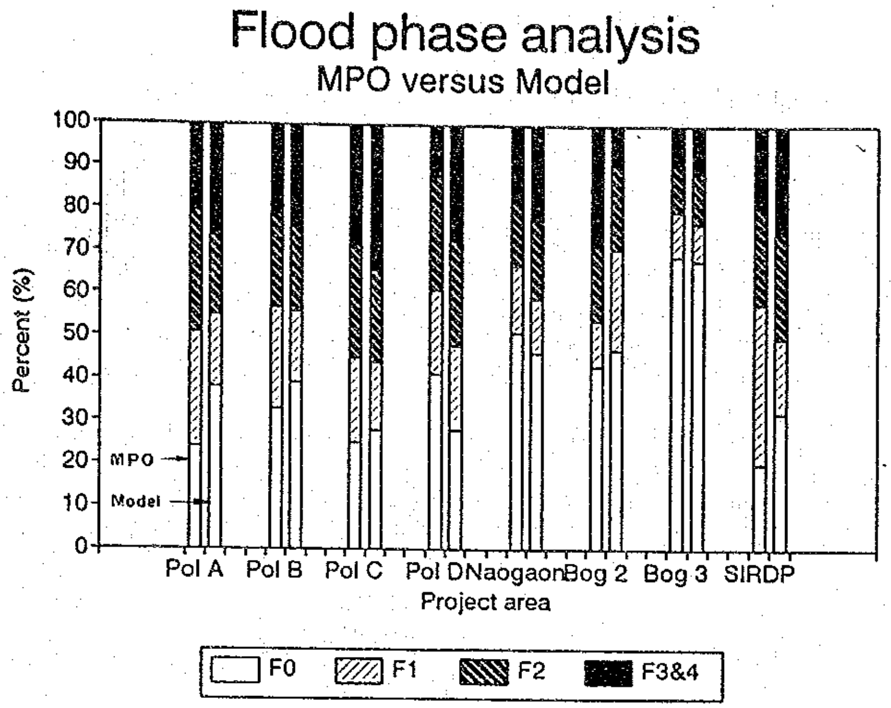


Figure 6.2 Verification of flood phase analysis

CHAPTER 7

IMPACT OF SEALING THE BRAHMAPUTRA RIGHT EMBANKMENT

7.1 Description

Once the sub-regional model had been calibrated and validated a simulation was carried out to investigate the impact of sealing the Brahmaputra Right Embankment (BRE). It was agreed with FPCO and FAP-25 that, of the developments proposed by other studies within the Flood Action Plan, this was the one which would have the greatest impact on the North West region. This simulation assumed that there were no internal developments within the area covered by the sub-regional model.

This simulation was for a 25 year period and used the hydrological data from 1965 to 1989. The objective of the model was to produce data on water level and discharge variations over a period of 25 hydrological years with the BRE sealed. The objective was not to simulated observed water level and discharge variations over the 25 year period from 1965 to 1989.

7.2 Model results

Impact on water levels

Sealing the BRE has minimal impact on water levels in the Lower Atrai basin. In the upper part of this basin water levels are determined by local flow conditions which depend on the geometry of the channels and rainfall runoff processes; they are not affected by water levels or spills from the main rivers. The central part of the Lower Atrai basin is an interaction zone where the water levels are affected by both local fluvial conditions and tail water levels. Since neither of these processes are affected by sealing the BRE the water level hydrographs in this area are not dependent on whether or not the BRE is sealed.

In the lower part of the Atrai basin water levels are tail water controlled; they are dependent on water levels in the Brahmaputra. Since the amount of flow which passes through the BRE breaches is small compared with the total flow in the Brahmaputra, the levels in the Brahmaputra will not changed significantly by the sealing of breaches and, hence, levels in these lower reaches of the Atrai river will similarly not be affected. Water levels in the Lower Bangali, likewise, are tail water controlled by levels in the Brahmaputra and these reaches will not be affected by sealing the BRE.

The area where the sealing of the BRE has the greatest impact is the Middle Bangali basin; here water levels are significantly reduced.

The impact of sealing the BRE on water levels in the Middle Bangali is illustrated in Figures 7.1 to 7.5. These figures show hydrographs at key locations with and without the BRE sealed. These hydrographs are for the 1988 flood season; this season was chosen because it was one of high water levels in the Brahmaputra and thus the impact of sealing the BRE would be at its greatest.

Sariakandi, Figure 7.1, is immediately downstream of where the flow through the main BRE breaches at Fulchari enter the Bangali system. At this location the reduction in peak water level as a result of sealing BRE is in excess of 1 m. Reductions in water levels of this magnitude occur throughout the flood season from early July until the end of October. There are also smaller reductions in water level, as a result of sealing the BRE, throughout May and June. The recession of the water level hydrograph during October is slightly quicker with the BRE sealed.

Similar trends were found throughout most of the Middle Bangali. At Khanpur and Raiganj which are about 15 km to 20 km west of the BRE, the impact of sealing the breaches again reduced peak levels by approximately 1 m. Much of the water which flows through the BRE breaches flows as overland flow across the flood plains and along minor drainage channels in a northeast-southwest direction. Sealing the BRE breaches prevents much of this overland flow and also reduces spillage on the right bank of the Ichamati which would have entered the Bangali in the vicinity of Khanpur and Raiganj.

Moving further downstream, the impact of sealing the breaches becomes less marked due to the backwater influence imposed by the Brahmaputra at the outfall of Bangali in to the Hurasagar. This can be seen at Ullapara, Figure 7.2, whereby the impact of sealing the BRE on water levels is seen to be greatly reduced.

Figure 7.3 and 7.4 show longitudinal profiles of peak levels along the Bangali and Ichamati rivers. It is clear from these longitudinal profiles that the sealing of the BRE result in significant reductions in peak water level.

Impact on discharges

The impact of sealing the BRE on discharges in the Middle Bangali and Lower Bangali basins is illustrated in Figures 7.5 and 7.6. These figures show discharge hydrographs at key locations within these basins with and without the BRE sealed. To ensure compatibility with the water level hydrographs presented above these hydrographs are also for the 1988 flood season.

At Sariakandi, Figure 7.5, the peak discharge is reduced from about 5000 m^3/s to less than 1000 m^3/s as a result of sealing the BRE; it must be noted that these discharges include the considerable overland/floodplain flows and not just that in the river system itself. With the breaches in the BRE the discharge at Sariakandi is in excess of 1000 m^3/s throughout the period from early July until mid-September. With the BRE sealed the discharge at Sariakandi only exceeds 500 m^3/s for approximately three weeks in September.

Similar reductions in flow were also seen at Khanpur, where the peak discharge is reduced by approximately 50 % from 850 m^3/s to 400 m^3/s, and at Nalkasengati, where the average discharge throughout the flood season is reduced by approximately 50 % from 800 m^3/s to 350 m^3/s.

Despite having only a minor impact on water levels, Ullapara discharges are reduced significantly and average flood season discharge is reduced by approximately 50 % and the peak discharge is reduced from 2500 m^3/s to 700 m^3/s, Figure 7.6.

It is clear therefore that sealing of the BRE results in a significant reduction in peak flows throughout the Middle and Lower Bangali basins and will give relief to the drainage congestion at the outfall of the Hurasagar.

FAP-1 assessment of flooding due to breaches

FAP-1 used a 1-D hydrodynamic model (MIKE11) of the right bank floodplain of the Brahmaputra which included the Middle and Lower Bangali basins to determine the impact of flooding due to breaches occurring at different locations in the BRE (Ref 7.1).

The impact of breaches at six sites were investigated by FAP-1; these breaches were at the same location as those used during calibration of the sub-regional model. The actual breach locations were Fulchari, Mathurapara, Kazipur, Sonali, Sirajganj and Betil. As well as investigating the impact of

each individual breach FAP-1 also investigated the composite impact of all breaches. The results of their investigation is summarised below.

Compared with the case of no breaches the total flooded land increases by approximately 30 % when all six breaches in the BRE are considered. The total flooded area is not significantly increased by the opening of any single breach, but, for some of the breaches the areas flooded to different depths does change significantly.

The breaches at Sonali, Sirajganj and Betil have little impact on the distribution of land flooded to different depths. The breaches at Kazipur, Fulchari and Mathurapara result in an increase in deeper flooded land relative to shallower flooded land.

The breach at Mathurapara has the greatest single effect; this single breach results in an increase in land flooded to a depth of more than 0.6 m of more than 100 %. The breaches at Fulchari and Kazipur respectively have the next greatest effects on the proportion of deeply flooded land.

With all the BRE breaches open approximately 80 % of the flooded land is flooded to depths in excess of 0.6 m. With all the BRE breaches sealed only 30 % of the flooded land is flooded to depths in excess of 0.6 m. It must also be noted that the total flooded area is 30 % greater when all the BRE breaches are open than when the BRE is sealed.

Flood phase analysis

Using the method described in Chapter 6, the flood phases for the Middle Bangali project area were calculated under present conditions and with the BRE breaches sealed. The results of this analysis are presented in Figure 7.7. In an average flood year, 1985, the area of F0 and F1 land is greatly increased from less than 60% to over 90%. In a much more severe flood year, 1988, the increase in F0 and F1 land is changed from below 20% to over 60% if the breaches in the BRE are sealed.

This analysis supports the results found by FAP-1 that the area of deeply flooded land is significantly reduced by the sealing of the breaches in the BRE. With the BRE sealed a very large percentage of the Middle Bangali project area falls within the F0 and F1 flood phase categories. Flooding within these flood phase categories is not, in general, a restriction to agriculture and the sealing of the BRE therefore reduces the flooding in the Middle Bangali project area to such an extent that it effectively eliminates flooding as a major problem in average flood years.

7.3 Morphological impact of sealing the BRE

7.3.1 The Bangali river system

The main rivers in the Middle Bangali planning unit are the Bangali, the Ichamati and the Karatoya. The rivers follow an essentially north-south course draining water to the Hurasagar and eventually the Brahmaputra.

In the early 1960's the Brahmaputra right embankment was constructed to prevent water and sediment spilling out from the Brahmaputra into the Bangali river system. This would have had a significant impact on the rivers in the region; since the construction of the BRE the rivers of the Middle Bangali basin will have adjusted to these conditions.

In the absence of spillage from the Brahmaputra through the breaches in the BRE the major sources of sediment is that brought into the system by the Bangali and Karatoya rivers.

To study the morphological conditions in the Bangali river system the sediment transport option of MIKE11 was run, for selected years, to indicate the quantity of sediment transport that occurs throughout the system. MIKE11 output was also used to determine regime discharges and hence used to study the existing river regime and how this regime would be altered by future developments.

Where the Ichamati spills from the Bangali a large proportion of the sediment passes down the Ichamati. This sediment returns to the Bangali at the confluence with the Ichamati downstream, near Nalkasengati.

Sediment transport rates in the Lower Bangali and the Durgadah, which spills from the Bangali a short distance upstream of its confluence with the Ichamati, are low. This is probably due to backwater effects from the Hurasagar caused by high water levels in the Brahmaputra. It is likely that this results in long term sedimentation in this area. No historical information which would have confirmed this was identified during the study.

Regime calculations were carried out using the discharges generated by MIKE11. At locations where spills through the BRE breaches have little impact on discharge, for example, at Bogra and Mohimaganj, the predictions of regime theory for width and depth give satisfactory agreement with the surveyed cross-sections.

7.3.2 Impact of spills through BRE breaches

A major recent impact on the morphology of the rivers in the Middle Bangali basin has been the development of breaches in the BRE during the 1980's. These breaches have had a major impact on the magnitude and distribution of flows in the rivers of the region; this is described in Section 7.2. The spills through the BRE have also introduced large quantities of sediment into the rivers of the region.

The larger discharges in the Bangali appear to be causing a localised backwater effects, upstream of the major breach locations, on the Bangali river. The reduced flow velocities and increased flow depths are reducing sediment transport rates at Mohimaganj. It is likely, therefore, that the spills from the Brahmaputra are causing sediment deposition in this reach. A similar effect appears to be occurring in the Ichamati causing sediment deposition in the reach upstream of where the breach channel from the Kazipur breach meets the Ichamati.

Downstream of Simulbari, in both the Bangali and the Ichamati, the flows and sediment transport rates are significantly increased. The increased quantities of sediment being transported within the system are likely to be deposited in the Lower Bangali at points where water levels from the Hurasagar exert an influence.

Regime calculations were carried out using the discharges generated by MIKE11. In those reaches which are affected by spills through the BRE breaches, the results assuming no spills predict widths and depths which are smaller than those observed. This suggests that the morphology of these reaches of the river is being affected by spills from the Brahmaputra. If the existing conditions are maintained in the region and spills continue through breaches in the BRE then it is likely that the affected lengths of the Bangali and the Ichamati will be subject to change. The channel widths and depths will increase and the plan form of the river will become more sinuous.

It would appear that the Middle Bangali river system is still adjusting to this change in the flow and sediment regime which has resulted from the breaches in the BRE. The present system should therefore not be regarded as being in equilibrium; continuing morphological development should be expected if the present conditions are maintained.

7.3.3 Impact of sealing the BRE breaches

If the breaches in the BRE are closed it is likely that the rivers of the Middle Bangali basin will return to conditions similar to those that existing prior to breaching.

It is unclear whether or not the present morphology of the Bangali river system is 'in regime' with the increased flows and sediment which passes through the breaches in the BRE. Given this situation it is not possible to state precisely what the impact of sealing the BRE on river morphology will be.

If it were assumed that the rivers of the Middle Bangali basin are 'in regime' with the present conditions the likely impacts of sealing BRE breaches are,

- enhanced sediment transport in reaches immediately upstream of where the breach channels join the main river system.
- reduced sediment transport in the downstream reaches of the Bangali and Ichamati.
- reduced sediment deposition in the reaches of the Lower Bangali where there is a backwater effect from the Hurasagar.
- a decrease in channel width and depth in those reaches which are affected by spills through the BRE breaches.
- in the reaches which are affected by spills through the BRE the river will exhibit a tendency to follow a straighter course.

In addition to these changes in the morphology of the Bangali river system, the sealing of the BRE breaches will reduce sediment deposition in the areas immediately behind the breaches and also in the areas adjacent to the breach channels.

Sealing of the breaches in the BRE adjacent to the Middle Bangali basin will not have an impact of the morphology of the Brahmaputra river.

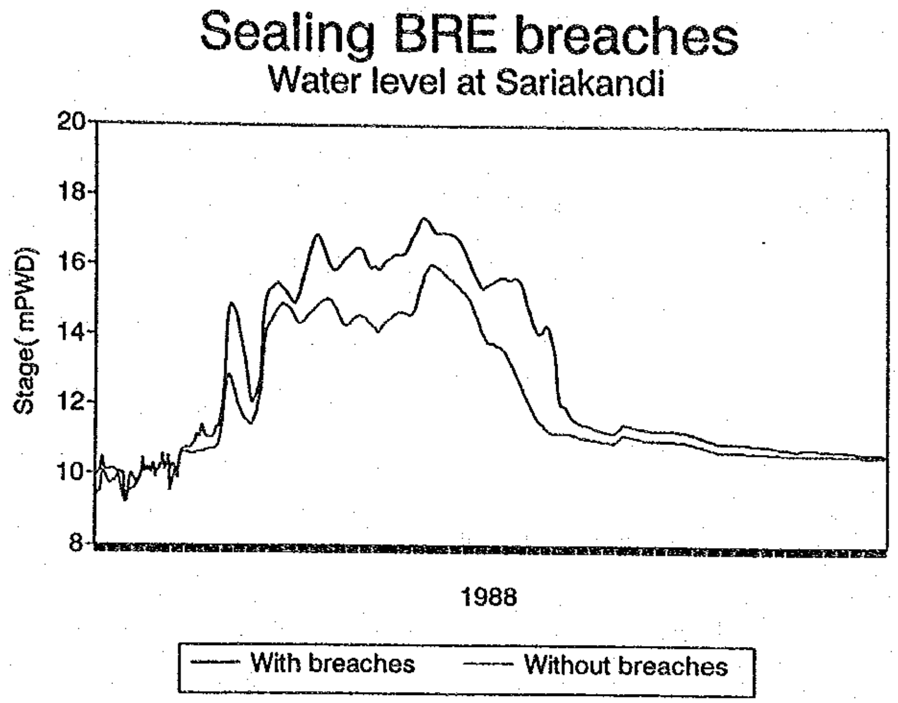


Figure 7.1 **Impact on water levels at Sariakandi**

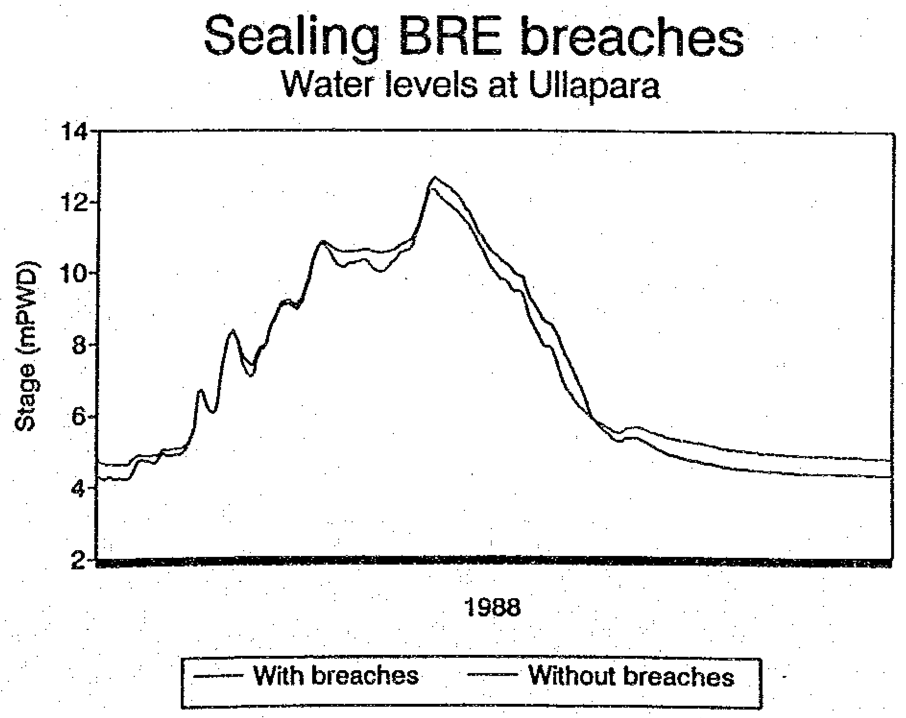


Figure 7.2 **Impact on water levels at Ullapara**

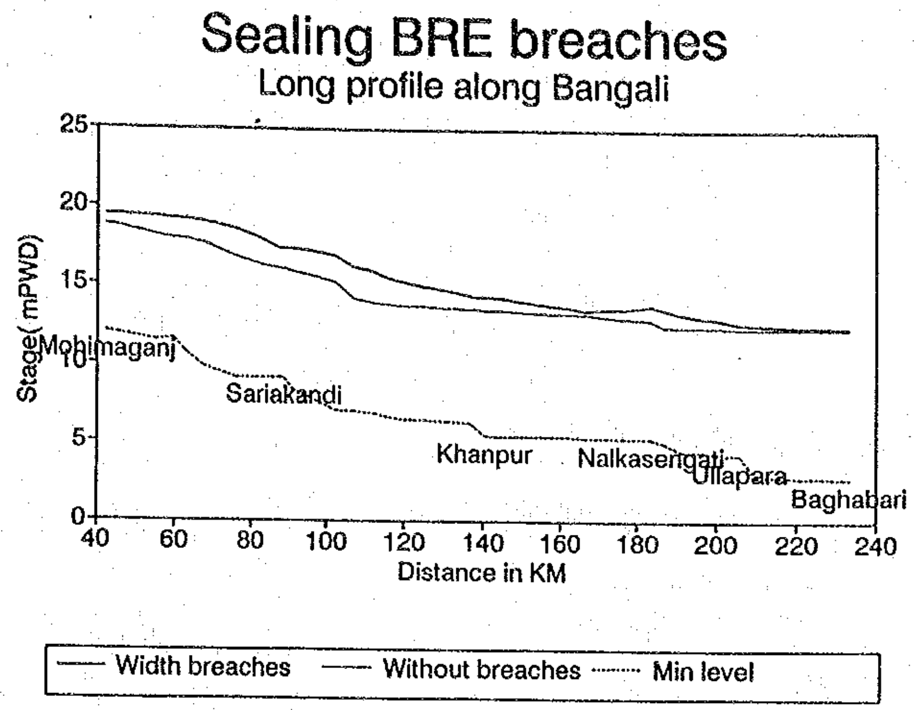


Figure 7.3 Impact on water levels along the Bangali

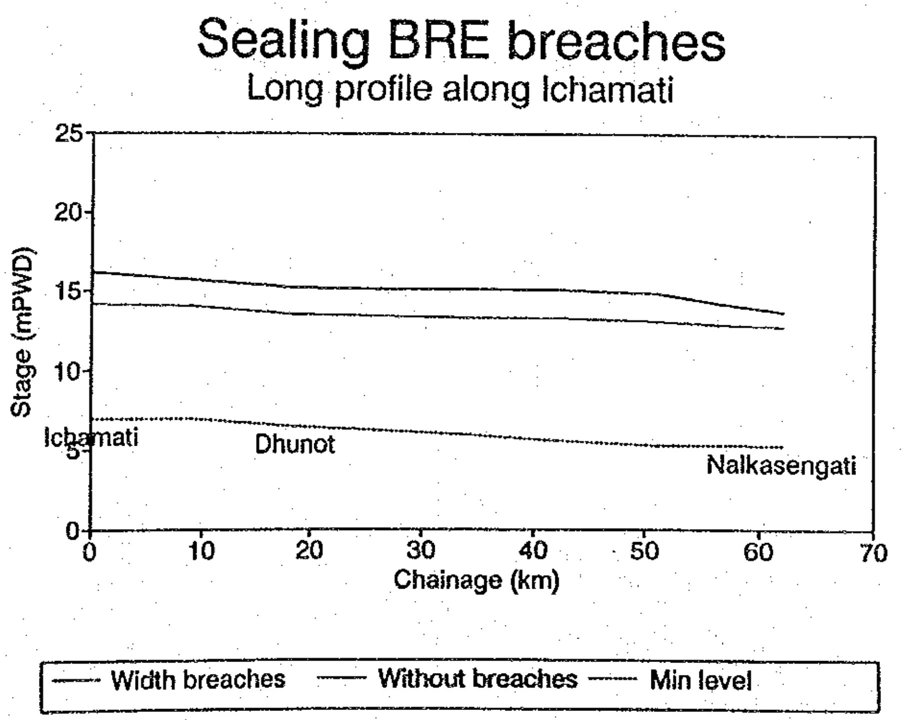


Figure 7.4 Impact on water levels along the Ichamati

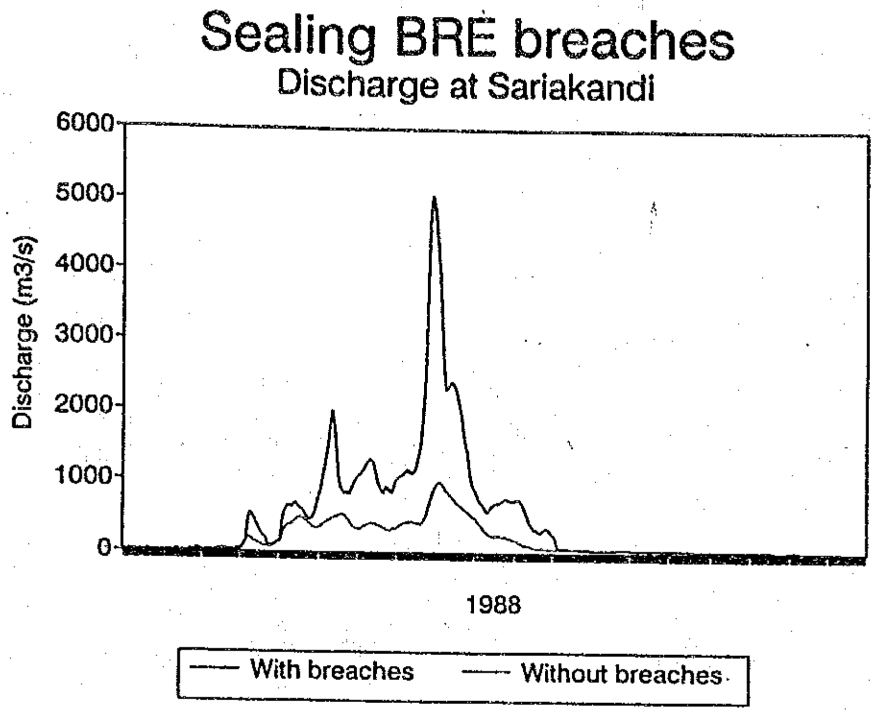


Figure 7.5 **Impact on discharges at Sariakandi**

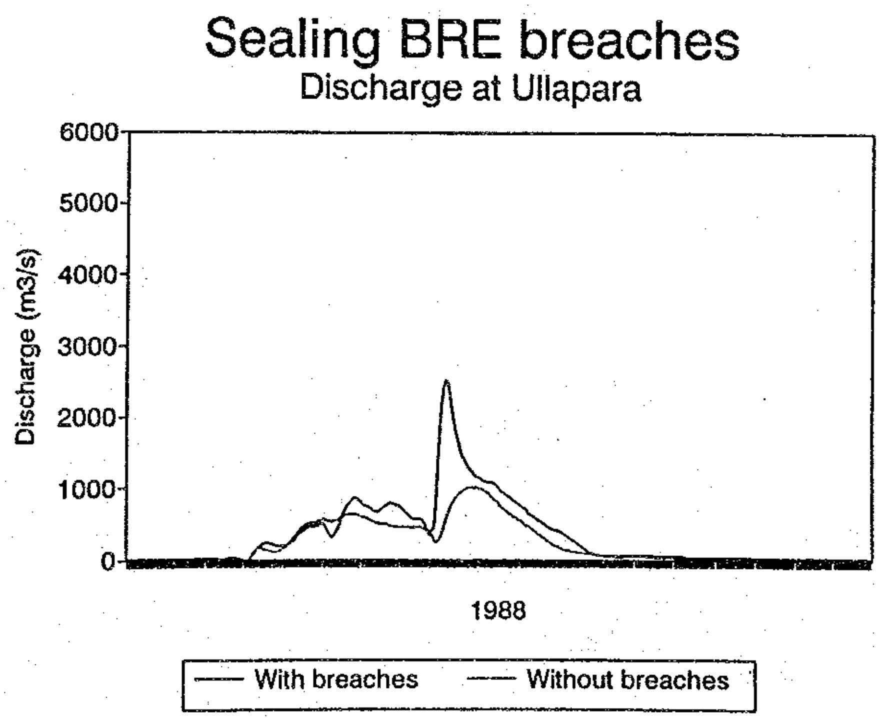


Figure 7.6 **Impact on discharges at Ullapara**

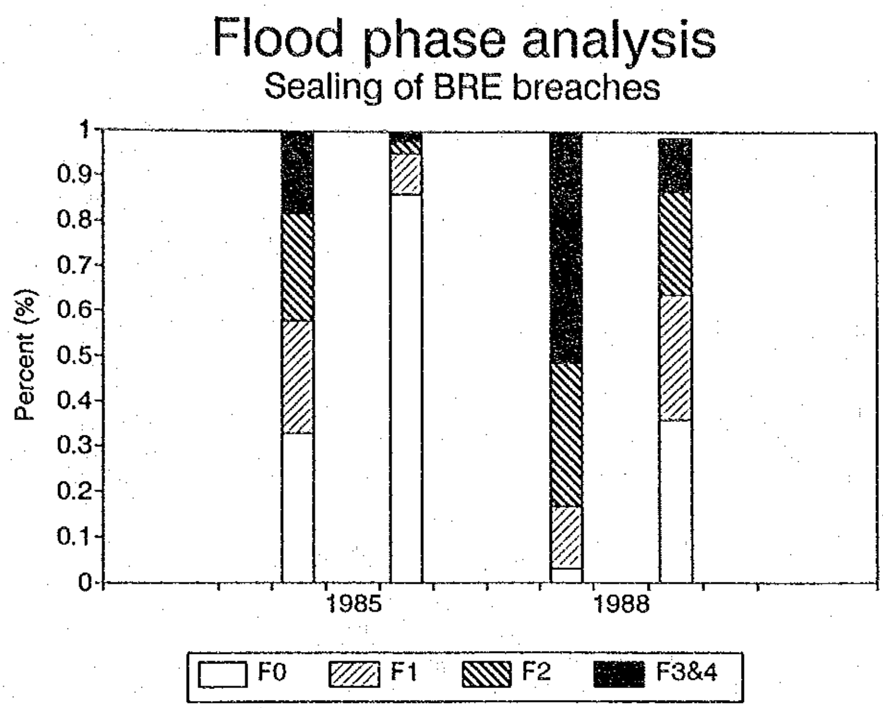


Figure 7.7 Flood phases with BRE sealed

CHAPTER 8

SUB-REGIONAL MODEL -WITHOUT PROJECT CONDITION

8.1 Description

8.1.1 General

It must be stressed that the objective of the Without Project simulation was not to simulated observed water level and discharge variations over the 25 year period from 1965 to 1989. It was to produce data on water level and discharge variations over a period of 25 hydrological years. This simulation included future developments within the sub-regional model area, which are at or near completion, together with external future developments, such as

- the completion of Naogaon polder
- the completion of the Barnai project
- the sealing of the BRE

This simulation provides baseline data for investigating and comparing the impacts of developments proposed as part of the NWRS.

The impacts of sealing the BRE are discussed in detail in Chapter 7.

8.1.2 Boundary conditions

In order to carry out a 25 year model simulations 25 years of hydrological data were required at the model boundary locations for the period 1965-89. This information was not available at all boundary stations. At discharge boundaries where water level, but not discharge data, was available for the required duration rating equations were used to generate the required hydrological information. At all boundary stations consistency checking and some infilling was carried out to obtain a complete dataset.

At Baghabari, the downstream water level boundary, it had been planned to use the simulated water levels from Run 6 of the General Model carried out by FAP 25. Analysis of the Run 6 model results at Baghabari, however, revealed that the peak water levels were generally lower, by over 0.7m in some cases, than those observed. In addition the 1:20 year one day maximum level generated from the FAP 25 results was about 0.5m lower than that calculated from the observed data; although this should be viewed with slight caution as the observed data set only extends for about 12 years.

Use of this FAP 25 data would have resulted in statistically unrepresentative water level results in the Lower Atrai and this would have implications regarding levels of flood protection and the costings of associated works. Bearing this in mind, the NWRS team decided to use observed water levels at the downstream boundary. Where the observed data was not available at Baghabari the boundary data was synthesised from nearby stations which had a longer records. This was felt to be acceptable as this area is totally dominated by backwater and the water level slopes are very small.

8.1.3 Internal developments

The internal developments which were simulated in the Without Project simulation are the Barnai project and the Naogaon Polder project. For the purposes of this simulation it is assumed these projects are completed as planned and that they continue to function as planned in the future.

The Naogaon Polder Project is between the river Atrai and the Little Jamuna on the north bank of the Atrai. The majority of the embankments for the project are complete. The regulators at the downstream end of the project are currently being constructed. The regulators together with the remainder of the embankments should be completed within the next year.

The Barnai project is on the south side of the Shib-Barnai river. It extends from approximately 5 km upstream of Nowhata in the west to Naldanga railway bridge in the east; the eastern limit of the project is the railway line. All the embankments and regulators of the Barnai project are now completed; the project was operable from the 1992 monsoon season.

8.2 Impact of internal developments

Naogaon Polder

Under present conditions Naogaon Polder acts as a flood storage area on the north bank of the Atrai. As water levels in the Atrai rise flood waters spill into Naogaon Polder. This water is stored in the polder until a reduction in water levels in the Atrai permit drainage. By acting as a flood storage area Naogaon Polder will result in some degree of flood attenuation along the downstream reaches of the Atrai.

Figure 8.1 illustrates the impact of closing Naogaon Polder on water levels in the Atrai. This figure shows water level hydrographs for 1987 at Rasulpur which is adjacent to the Naogaon Polder regulators with Naogaon Polder open and closed. Hydrographs for 1987 are used in this figure since in 1987 flooding problems resulted from high river flows rather than backwater effects. The parts of the Atrai basin which will be affected by the closing of Naogaon Polder are in the fluvial zone - water levels predominantly depend on the flow in the river.

Completion of Naogaon Polder does not have a dominant effect on water levels in the Atrai. Under present conditions water passes into Naogaon Polder as the Atrai levels rise. Closure of the polder opening results in a increase in water levels on the rising limbs of the hydrograph. Under present conditions, as water returns from storage the recessions limbs have a slower fall off rate, and this can be particularly seen on the final recession. At peak levels, completion of Naogaon Polder has little affect. The impact of sealing Naogaon Polder on water levels further downstream is likely diminish because in these lower reaches the levels become dominated by backwater effects rather than fluvial flows entering from upstream reaches.

Barnai Project

Under present conditions the area covered by the Barnai project acts as a floodplain which, under monsoon conditions, conveys flow parallel to the Shib-Barnai river along the northern border of the project area. The sealing of the Barnai project will eliminate this flood plain as a spillage/flow area. This will result in a reduced cross-sectional area of flow and is likely to raise water levels in the river system.

A long profile along the Shib-Barnai is shown in Figure 8.2 and this clearly illustrates the impact of completion of the Barnai project on water levels in the Shib-Barnai, for 1987. In 1987 flooding problems resulted from high river flows rather than backwater effects from the Brahmaputra and this demonstrates best the impact of confinement effects.

At Nowhata, about 5km downstream of the western limit of the project, peak water levels are increased by about 0.8 m. At Bagmara, at the confluence of the Barnai and the Fakirni, the impact

is very similar to that at Nowhata with peak water levels increasing by around 1 m.

The water level hydrographs at these locations indicated that levels would be increased throughout the period from early July until mid October. The hydrographs at Bagmara also showed that the fluctuation in water levels was greater after completion of the Barnai project as the attenuating effect of the flood plain on the right bank of the Shib-Barnai has been removed.

Water levels in the Fikirni were also seen to be affected with levels rising to the same order as those in the Shib-Barnai and this could affect the drainage from Polder D in to the Fakirni. There is also an increase in levels along the Shib to the west of Polder D; which is a location where numerous public cuts having taken place in the past. The drainage flows across Polder D, however, are unlikely to reduce significantly as the diffential head between the boundary rivers will remain similar. Nevertheless, water levels within Polder D are likely to be increased, particularly if the polder embankments area cut or breached.

Comparison of the discharge hydrographs at Nowhata and Bagmara revealed that discharges will reduce at both sites. At Nowhata the impact is only slight whereas at Bagmara the impact is significantly greater. This is accounted for by the fact that the main source of flow in the Shib-Barnai river is rainfall-runoff. The embankments of the Barnai project reduce the runoff which reaches the river from the right bank and the higher levels in the upper reaches of the Shib will allow more water to go in to temporary storage either within Polder D or at the foot of the Barind area to the west. There may also be an impact of reduced flows from the Atrai down the Fakirni due to the higher tail water levels at Bagmara.

Chalan Beel Polder D

One area in which the raising of water levels along the Shib-Barnai will have a significant impact is in Chalan Beel Polder D. This is best illustrated by considering the flood phases with and without the completion of the Barnai Project, Table 8.1 and Figure 8.3.

TABLE 8.1

Flood phases in Chalan Beel Polder D with and without the Barnai project closed

	Without Barnai project closed	With Barnai project closed
F0	28 %	17 %
F1	20 %	21 %
F2	25 %	27 %
F3 + F4	27 %	35 %

The rise in water levels in the Shib-Barnai and downstream reaches of the Fikirni which result from the closing of the Barnai project make the flooding conditions in Chalan Beel Polder D significantly worse; this analysis assumes the western embankment is cut. As far as agricultural productivity is concerned the percentage of F0 and F1 land is critical. Completion of the embankments on the Barnai project reduces this from 48% to 38%.

8.3 Analysis of results of Without Project simulation

8.3.1 Water levels

Hydrological analysis was carried out on the 25 year time series of water levels at key points within the Lower Atrai basin. The results of the Without Project simulation were analysed on a 10 day basis to give minimum, mean and maximum water levels for each decade. In addition, return period water levels were calculated for 2, 5, 10, 20, 50 and 100 years.

The water levels with different return periods were compared with those calculated from field observations; this comparison indicated that levels in the Atrai would remain similar to those at present. In making such a comparison it must be recalled that the Without Project simulation assumes the presence of the breaches and public cuts which occurred during the 1991 monsoon period throughout the 25 years of model simulation. In reality the breaches and public cuts will vary from one season to the other; significantly different drainage patterns may have occurred in the past.

Figure 8.4 shows the maximum level envelope of peak levels along the Atrai river for the five year simulation 1985-89. The figure clearly demonstrates the strong backwater influence of the Brahmaputra which dominates throughout most of the middle and lower reaches. The peak levels are approximately the same as those for present conditions in the Lower Atrai.

The completion of the Naogaon Polder Project and Barnai Project in the Lower Atrai basin will have no impact on water levels in the Middle and Lower Bangali basins. The Without Project conditions in these basins are exactly the same as those in the simulation with the BRE sealed; this simulation is reported in Chapter 7.

8.3.2 Discharge distribution

The maximum discharges simulated in the Without Project run in the main channels and drainage routes in the Lower Atrai basin are shown in Figure 8.5.

Approximately 50% of the flow in the Shib-Barnai river passes through the breaches in the west embankment of Chalan Beel Polder D. This flow passes across the polder, spills into the Fikirni river and rejoins the Shib-Barnai at Bagmara. Approximately 30% of the flow in the Atrai passes down the Fikirni, into the Shib-Barnai at Bagmara, and rejoins the Atrai at Chanchkoir.

A short distance downstream of Jotebazar approximately 25% of the remaining flow in the Atrai spills into Chalan Beel Polder C through breaches. This flow passes across the polder and rejoins the Atrai a short distance downstream of Singra. A large discharge also flows parallel to the Atrai river across the lower parts of Bogra Polders 2 and 3. This flow continues across the Bhadai river and Bogra Polder 4 before passing through the Taras embankment and into the lower parts of SIRDP. Flow also occurs parallel to the Atrai on the southern bank in the lower reaches of Chalan Beel Polders A and B.

Hydraulically the Lower Atrai basin can be thought of as consisting of three parallel drainage paths with the central one being the Atrai. On the southern side the drainage path is across the Chalan Beel Polders whilst on the northern side it is across the Bogra Polders and into SIRDP.